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# Offshore Hydrocarbon Exploration and Development

## ... a preliminary environmental assessment

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Ministry of Environment

# A PRELIMINARY ENVIRONMENTAL ASSESSMENT OF OFFSHORE HYDROCARBON EXPLORATION AND DEVELOPMENT

prepared by
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# EXECUTIVE SUMMARY

This Preliminary Environmental Assessment was conducted by the Planning and Assessment Branch of the British Columbia Ministry of Environment. It identifies and evaluates the environmental implications of offshore hydrocarbon exploration and development for British Columbia, with emphasis on the North Coast. The report is based on a comprehensive literature review and consultation with technical experts. It addresses impacts during three phases of offshore petroleum activity: seismic exploration, exploratory drilling, and production. Because the report considers potential impacts of the development of offshore hydrocarbon resources, its scope is more comprehensive than if it considered exploration activities alone. The report identifies the key issues and data gaps (see Chapter 6), thereby providing the basis for further environmental impact assessment, planning and management of offshore development.

## MAJOR FINDINGS

### GENERAL

British Columbia's marine and coastal resources in the area proposed for exploration are highly valuable in ecological, commercial and recreational terms.

1. Offshore and related onshore activities will affect British Columbia's coastal resources and the communities which depend on them. Exploration and development of hydrocarbon resources in this area and the related onshore support activities could have some impact on these resources. Because of recent improvement in exploration technology and safety measures, impacts during exploration are considered to be small. Commercial development of hydrocarbon resources poses greater risks from both routine operations and non-routine events such as spills or blowouts. Thus, proposals

for development will require a different focus on analysis than will the initial exploration phase.

2. There are many gaps in our understanding of the biophysical characteristics of the west coast. Traditionally, impact assessments have been based upon extensive descriptions of environmental resources. British Columbia can learn from offshore experiences elsewhere to help focus the collection of biophysical and oceanographic information on specific issues and resources in a cost-effective manner.
3. Impact assessment will not be able to answer all environmental protection questions due to uncertainty as to the nature of location of offshore petroleum fields in B.C., and imperfect knowledge of coastal processes. Comprehensive project planning, monitoring and surveillance is required to ensure effective environmental management of offshore activities.

## PHYSICAL ENVIRONMENT

The physical environment of the North Coast poses substantial challenges and risks for offshore exploration and development. Much of this area, especially the west coast of the Queen Charlotte Islands, remains poorly understood in terms of its meteorological, geophysical and oceanographic characteristics. Extensive data-gathering will likely concentrate in the areas of interest for offshore exploration (Dixon Entrance, Queen Charlotte Sound and Hecate Strait). Information will also be needed for other coastal areas that might be directly or indirectly affected by offshore development.

### Conclusions

1. Much of the information on physical environment necessary for a comprehensive assessment, planning and management of offshore activity is inadequate or is not in an appropriate form for analysis. The categories for which existing data are inadequate

are: wind speed, wind duration, wind direction, current speed, current direction, wave height, wave period, fog, sea surface elevation, coastal geomorphology, seismicity, bathymetry and tidal amplitude.

2. Seismic activity is considered a significant risk for offshore activity in British Columbia; however, the centre of seismic activity lies along the west coast of the Queen Charlotte Islands and drilling is anticipated on the north or east coast. The remoteness of the possibility of a seismic event during drilling and the effectiveness of the technology available to avoid a seismically induced blowout reduce this risk considerably. Risk analysis and design engineering must take seismicity into account however.
3. The severe winds and high wave conditions off the B.C. coast must also be addressed fully in assessing west coast offshore activity and in designing any offshore system.

## BIOLOGICAL ENVIRONMENT

The wide variety of marine, estuarine and intertidal areas in the study area provide productive habitats for fish, shellfish, birds, mammals, plankton and other marine organisms. The consideration of offshore activity in British Columbia take into account the potential impacts on the commercial and cultural value of these biological resources.

### Conclusions

1. Experience elsewhere has indicated that with strict environmental regulation of routine offshore operations, most offshore biological impacts can be avoided or mitigated. Discharge of ballast tanks, bilgewater, formation water and some drilling muds is of some

concern, especially in poorly flushed areas. Monitoring and surveillance programs are required.

2. There is a lack of inventory and ecological information for many plant and animal species on the North Coast. A focussed inventory and research program to be carried out jointly by federal and provincial agencies, and proponent companies is required to enable detailed environmental assessment of specific drilling proposals.
3. Many biological resources of the British Columbia coast are susceptible to impacts from spills or chronic marine pollution. Of these, bird feeding and nesting grounds, fish spawning areas, and intertidal communities are most susceptible. The possibility of fish tainting or of effects on salmon migration through estuaries warrants investigation.
4. Coastal sensitivity mapping is an important part of impact assessment and contingency planning. This mapping takes into account the range of susceptibility of different organisms and habitat types to oil pollution.

## ONSHORE IMPACTS

Onshore activities include servicing facilities required to support offshore exploration and development. Potentially the environmental impacts of onshore activities are of as much concern as routine offshore impacts. However, the level of impacts is highly dependent upon the scale and type of land-based facilities required.

### Conclusions

1. Onshore impacts during exploration would be minimal if the supply and servicing base were located at an existing port. Onshore impacts are of greater concern during the production stage if land-based facilities are expanded, and if oil and gas related

activities such as a pipeline, gas processing plant or oil refinery, are proposed.

2. Impacts on onshore facilities can be minimized through comprehensive, early planning to ensure environmentally sensitive siting and design. In British Columbia, this planning should be coordinated with the management of existing and proposed coastal activities related to fishing, shipping, tourism and industry.
3. The effects of offshore and related onshore development on other coastal resource-based activities such as mariculture, recreation, tourism and particularly fishing, are of concern in British Columbia. Experience elsewhere indicates that effective planning and mitigation/compensation programs can address many of these concerns. The fishing and mariculture industries must receive priority attention in offshore hydrocarbon assessment and planning for the British Columbia coast.

## OFFSHORE RISK ANALYSIS AND CONTINGENCY PLANNING

1. The risk of blowouts or other offshore exploration activities contributing to major oil spills on the British Columbia coast is expected to be small. The highest risk of oil spillage will likely come with product handling and marine transport, should significant quantities of oil be discovered.
2. Accidents resulting in oil spills result primarily from natural hazards, mechnical failure and human error. Improved technology and training and improved maintenance and regulation reduces the risk of oil spills.
3. Oil spill contingency plans include comprehensive risk analyses to predict spill probabilities, spill distribution and potential impacts on the resources at risk. The feasibility of employing appropriate countermeasures for different spill scenarios must also be considered.

4. Characteristics of the B.C. coast which may increase risks to the environment from oil spills or other offshore activities are as follows:
    a. shallowness of the water column
    b. large tidal range
    c. high velocity currents
    d. wide littoral zones, susceptible to oiling
    e. highly productive fishery
    f. remote coastlines
    g. highly dissected coastline with many sensitive estuaries
    h. high incidence of fog
    i. high incidence of gale force winds
    j. low temperatures
    k. high incidence of seismic activity
    l. inadequacy of biological and physical oceanographic data

    Information gathering for risk analysis and contingency planning for B.C. offshore hydrocarbon development will need to focus on these factors.

## RECOMMENDATION

An Environmental Data and Information Forum composed of representatives of proponent companies, provincial and federal government agencies is required. The Forum is needed in order to identify and focus the environmental assessment requirements for each phase of offshore hydrocarbon development: seismic exploration, exploratory drilling, and production. The objectives of the Forum should be:

1. To assess the adequacy of existing environmental data to evaluate potential impacts and ways of mitigating these in the event that exploration and eventual development of offshore hydrocarbons should take place.
2. To coordinate the collection of additional data and information required to fill critical data gaps in the most cost-effective manner.

# PREFACE

This Preliminary Environmental Assessment has been conducted in order to identify and evaluate the environmental implications of offshore hydrocarbon exploration on the west coast of British Columbia. The Assessment Branch of the Ministry of Environment's Assessment and Planning Division has carried out this analysis on behalf of the Ministry. The report reflects the concerns of all branches of the Ministry of Environment and of other resource agencies.

The report addresses environmental concerns in relation to each of three phases of the offshore petroleum industry - exploration, development, and production. The conclusions reached from this analysis will be used as a basis for guidance of the environmental management of this industry should exploration activity resume on the West Coast.

## BACKGROUND

Petroleum exploration off the west coast of British Columbia began in the late 1960's. Approximately 15 million acres were allocated by permit, with the largest block of 13 million acres granted to Shell Canada Ltd. From 1967-1969, Shell carried out an exploratory drilling program of fourteen wells. No petroleum reserves were found and drilling was terminated. Subsequent seismic and geological interpretation led to interest in offshore petroleum resources by Chevron Canada who established a farm-out agreement with Shell. However, exploration could not be resumed due to a federal government moratorium on the granting of drilling permits. This moratorium was established in 1970 to support negotiations with the United States regarding the restriction of oil tanker traffic down the west coast from Prudhoe Bay.

In June 1981, the Province of British Columbia declared its interest in the Inland Marine Zone as an area of provincial jurisdiction over offshore petroleum resources. This area includes Dixon Entrance, Queen Charlotte Sound, Hecate Strait, Johnstone Strait, Georgia Strait and the Strait of Juan de Fuca.

The provincial government announced at the same time its commitment to a full social and environmental public hearing process prior to the beginning of any offshore exploration activities. A further reivew of the best means to develop the resource would follow if exploration were to proceed and lead to a significant discovery. Further, an indefinite moratorium was placed on exploration in Johnstone Strait south of Telegraph Cove, and in the Straits of Georgia and Juan de Fuca.

Since that time, Petro Canada has been nominated for Federal exploration rights in the Dixon Entrance area. However, to date the province has not issued permits in its area of jurisdiction.

The current exploration interests of Petro Canada and Chevron are focussed in North Coast waters. As a prelude to exploration activity, the Federal Department of Energy, Mines and Resources has required both companies to prepare an Initial Environmental Evaluation (I.E.E.) of proposed exploration programs. The I.E.E. is the first step in the process of environmental review of large-scale projects either involving federal sponsorship, funding or lands.

Proposals for hydrocarbon exploration and development off the coast of British Columbia will require careful scrutiny to determine their environmental impact. It is clear that offshore and related onshore oil and gas activities will pose a risk to British Columbia's coastal resources and the activities and communities which depend on them. Impacts could result from both routine (day-to-day) operations and non-routine events such as spills and blow-outs.

The physical environment of the North Coast poses substantial challenges and risks for offshore exploration and development. Among the foremost environmental constraints are seismic activity, severe winds, and high waves. The wide variety of marine, estuarine and intertidal areas in British Columbia provide productive habitat for fish, shellfish, birds, mammals, algae and other marine organisms. These biological resources have ecological, commercial and cultural value to individual coastal communities and to the province. Bird feeding and nesting grounds, fish spawning areas, and intertidal communities would be particularly susceptible to oil spills and chronic marine pollution.

Offshore hydrocarbon development can affect existing coastal activities such as fishing, aquaculture and recreation, and could limit future expansion of these activities. The environmental impacts of onshore servicing and processing facilities may also be significant, especially if facilities were located in a relatively undeveloped area. Offshore development has the potential to bring substantial environmental, social and economic changes to those communities adjacent to the offshore fields. Analysis of these three types of impacts should be closely coordinated to present an overall picture of what offshore development will mean for British Columbia.

## PRELIMINARY ENVIRONMENTAL ASSESSMENT

The objectives of this Preliminary Environmental Assessment (P.E.A.) of offshore hydrocarbon exploration and development are:

1) To identify the potential environmental impacts of offshore hydrocarbon development and evaluate their significance for British Columbia;
2) To evaluate the adequacy of existing information and data for comprehensive environmental assessment, planning and management of the offshore oil and gas industry;
3) To identify at an early stage, requirements for environmental assessment, planning and management for offshore resource development;
4) To determine what further questions will need to be addressed in order to:

a) adequately evaluate the environmental consequences of offshore development for British Columbia;
b) enable effective planning and management of offshore and related onshore oil and gas activities;

5) To provide the Ministry of Environment with a technical basis for evaluation of proposals for offshore exploration and development.

The area of focus includes the west coast of British Columbia, except for the Straits of Juan de Fuca and Georgia and Johnstone Strait south of Telegraph Cove on Vancouver Island, with particular emphasis on the North Coast (i.e., the area between the northern tip of Vancouver Island to the Alaska border).

This P.E.A. is based on a comprehensive review of literature and files and on consultation with key technical experts. The report addresses impacts during three phases of offshore petroleum activity: seismic exploration, exploratory drilling, and development (including construction and production).

The information is presented in six chapters. The first of these reviews the industrial activities involved in offshore hydrocarbon exploration and development, including drill rigs, the drilling process, oil and gas transportation, and onshore and offshore production facilities. Chapter two outlines the physical and chemical parameters of the offshore environment. It analyzes winds, waves, seismic activity, climate and other factors, particularly as they relate to constraints on the offshore industry. Chapter three describes the marine and coastal biological environments and highlights potential environmental impacts of offshore activities on various groups of organisms. Many of the areas of interest for exploration are close enough to the coast to pose some risk of impacts. Chapter four summarizes the environmental impacts which could result from the onshore facilities associated with offshore development. The need for careful planning, siting and construction of facilities is emphasized. Possible conflicts between oil and gas activities and existing coastal activities are also identified. Chapter five analyses risk information and contingency planning as they relate to oil spills and blow-outs. The final chapter presents the findings of the P.E.A. and highlights the concerns which have been identified during the investigation.

Throughout the report, particular attention has been paid to evaluating the adequacy of existing data and information and to identifying the questions yet to be addressed in assessing the environmental impacts of this activity. Data and information gaps are defined in terms of what knowledge would be needed to ensure that this industry is developed in an environmentally acceptable manner. The conclusions are summarized in Chapter six.

# A PRELIMINARY ENVIRONMENTAL ASSESSMENT OF OFFSHORE HYDROCARBON EXPLORATION AND DEVELOPMENT

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# CHAPTER 1

# OFFSHORE PETROLEUM DEVELOPMENT

Ken Baillie

# CHAPTER 1—OFFSHORE PETROLEUM DEVELOPMENT

## 1.1 PHASES OF OFFSHORE PETROLEUM DEVELOPMENT

Offshore petroleum operations fall into four distinct yet overlapping phases: exploration, development, production, and shutdown. The time frame for these operations ranges anywhere from 15 to 40 years depending on the particular oil or gas field. This chapter describes the facilities and activities associated with each phase.

The exploration period lasts from 1 to 8 years and extends from the granting of the lease to the time when commercially recoverable oil and/or gas reserves are located. If the exploratory rigs do not discover commercial quantities of petroleum, the exploratory phase is very short and lasts only until lease abandonment. If a marketable discovery is made, exploratory activities could continue for many years. The most intense exploratory drilling usually occurs within the first 5 years. This activity requires the establishment of service bases, heliports and other onshore facilities.

The development phase, which usually lasts from 4 to 20 years, encompasses those activities required to bring a field to the point of commercial production. This is the phase during which most of the construction activities occur. Facilities which may be built include offshore platforms, pipelines, tank farms, tanker terminals, and gas processing plants.

The production period lasts 5 to 25 years. Offshore wells which were drilled during development begin operating and the oil and/or gas is transported to shore for storage, refining or marketing. During this time, platform supply and maintenance operations must support constant (24 hour) production.

Shutdown activity occurs during the last 3 to 4 years of the operation as production begins to decline. Once the field is completely pumped dry, removal or conversion of the various facilities occurs in conjunction with the capping of dry wells and the abandonment of nonproducing fields.

## 1.2 SEISMIC SURVEY

One of the first steps taken by oil companies when considering offshore oil and gas exploration is to determine the hydrocarbon potential of a specific area. This is accomplished by conducting a seismic survey, which simply involves the bouncing of sound waves off the underlying rock formations. From the survey, cross sections and contour maps of subsurface structures can be pieced together which in combination with geological information can indicate the potential of the area.

The survey is usually conducted by a specially equipped vessel which travels along a specific grid pattern towing signal-generating and recording equipment. Because of their potential for adverse environmental effects, explosive materials such as dynamite are no longer used to generate the required sound waves. Substitutes utilizing gas (sleeve exploder) or electricity (electronic sparker) are now used.

Other types of seismic surveys are also conducted to determine areas where geological hazards such as faults and mudslides may occur. These surveys are important in selecting and establishing exploratory drilling areas, production sites and the design of platforms and pipelines necessary to service the field.

## 1.3 THE DRILLING PROCESS

Once a seismic survey has indicated the possible existence of oil/gas bearing strata beneath the ocean floor, exploratory holes are drilled to determine the extent of the field and the commercial viability of the find. A drilling rig is brought to an appropriate location and a template, or guiding frame, is set on the sea floor. A large diameter pipe, the "marine riser", is then run from the template up through the water to the rig floor. This riser pipe acts as a guide for the drill.

Next, the well is "spudded in" (started) by using a drilling bit lowered to the bottom through the marine riser which consists of 10 m lengths of steel pipe screwed together to form a drill string. The drill bit and complete drill string is rotated within the marine riser by machinery located on the drill ship. Gradually, the hole is deepened by the biting of the drill bit, and when necessary, additional 10 m sections of pipe are added to the drill string at the surface (Figure 1.2).

As the drill bit turns and grinds its way through the rock, drilling fluid (mud) is circulated down the inner hollow core of the drill string,

Plate 1: Drillships are commonly used for exploratory work in waters greater than 300 m in depth.

*(Petro-Canada photo)*

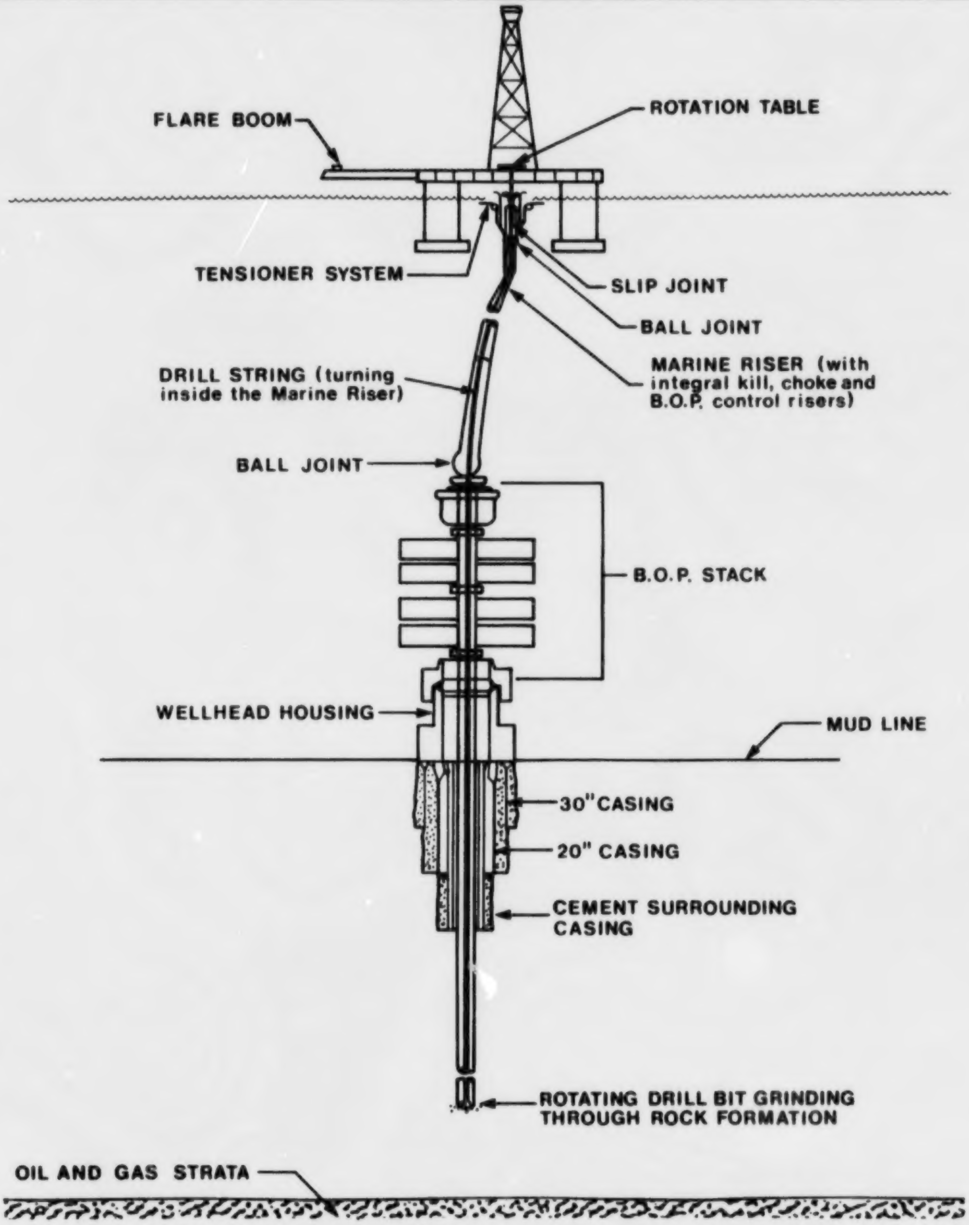

FLARE BOOM
ROTATION TABLE
TENSIONER SYSTEM
SLIP JOINT
BALL JOINT
DRILL STRING (turning inside the Marine Riser)
MARINE RISER (with integral kill, choke and B.O.P. control risers)
BALL JOINT
B.O.P. STACK
WELLHEAD HOUSING
MUD LINE
30" CASING
20" CASING
CEMENT SURROUNDING CASING
ROTATING DRILL BIT GRINDING THROUGH ROCK FORMATION
OIL AND GAS STRATA

FIGURE 1.1

**TYPICAL "SET UP" FOR EQUIPMENT USED IN OFFSHORE DRILLING**

Modified from: Petro Canada Exploration Inc., October 23, 1981, Grand Banks Environmental Overview around the grinding bit, and up the space between the drill string and the inside of the marine riser. These drilling fluids not only remove the rock cuttings from under the drill bit and transfer them to the surface for separation, but also cool and lubricate the bit and string to maximize the penetration rate. These drilling fluids are also important for coating the exposed walls of the drill hole (thus minimizing fluid loss into permeable rock formations) and for maintaining all rock cuttings in suspension if drilling or circulation is stopped. The various subsurface pressures that are encountered during drilling through different rock formations are balanced by adjusting the density (and therefore the weight) of the drilling fluid circulating through the drill string. This adjustment in density helps ensure that blowouts do not occur by constantly maintaining a pressure of approximately 150 psi (10 bars) greater than any natural subsurface pressure encountered.

A penetration rate of 45-50 m/day (150'-165'/day) is typical. Occasionally during the drilling of a well, steel casing (pipe) must be cemented in the hole. This casing provides a steel wall for the sides of the drilled hole, thus sealing off pressure and fluids from the underground formations through which the hole penetrates. To run (install) casing, the drill string is removed and each joint of similar diameter casing pipe is screwed together to obtain the length required. After the complete casing string is lowered to the correct depth, a cement slurry is pumped into the middle of the casing in an amount necessary to fill the space (annulus) between the casing and the walls of the drill hole. A movable plug is then inserted above the cement, and mud is pumped in to force this plug downwards. The slurry thus moves down, around the far end of the casing string, and up into the annulus space. Everything is then shut down for four to twelve hours, allowing the cement time to harden.

Once a hole has been drilled, the well must be evaluated as to whether or not there is enough oil present to complete it. This may be done electronically by a process called "logging", which measures the electrical potential, electrical resistivity and natural gamma radiation, or by the physical examination of the drill cuttings as they emerge from the hole.

If the well is commercially viable, the hole is drilled to the desired depth and all necessary casing is installed and cemented in place. This then allows the well to be "completed" (placed in a productive mode). One of the first steps in doing this is to perforate the oil and gas bearing formation with a perforating gun. This involves shooting holes through the production casing, the cement, and into the oil bearing rock formation. The perforations are made in the most productive sections of the formation, thereby allowing the oil to flow out of the surrounding rock, through the perforations, and into the casing.

After the well is perforated, a string of tubing is run inside the production casing. The natural formation pressure causes the oil to flow up through this tubing to the surface. Usually a special piece of equipment called a "packer" is used to seal off the spaces between the inside of the production casing and the tubing, thus forcing the flow into the tubing.

Sometimes a well will be drilled into two or more formations that produce different qualities of oil or gas. Since it is not efficient to allow these different products to mix, they are kept separate by a process called "multiple completion". This allows for the different products to be drawn off simultaneously from the same drill hole without mixing.

If the formations are too compact ("tight"), the production rate is too slow. This rate can be increased severalfold by fracturing the formation with a sand-laden fluid. The sand forces the fractures open and forms a permeable flow path through which the oil can travel. Such stimulation can also be accomplished by pumping acid down and into the formation.

Often, the formation consists of loose sand which can cause severe erosion problems and/or can plug various well and surface equipment. Two main methods can be used to control this. Coarse sand or gravel can be placed between the formation and the casing by using a special screen or liner. This allows the oil to escape but holds back the sand. An alternative method is to use plastic to glue the sand grains together. In this case, a solution of plastic is pumped into the formation. When this procedure is done correctly, the sand grains become stuck together and do not plug the pores through which the oil escapes.

Subsurface safety devices are used to shut off the flow of oil in the well automatically if an emergency occurs. One of these devices, a stack of valves known as a blowout preventer (or BOP stack) can slam shut in an emergency. It is usually bolted to the well head as soon as the first length of casing has been successfully cemented into place. All drilling and maintenance work is carried out through this BOP stack to ensure that the hole can be quickly sealed in case of a mishap.

On a production platform the role of the BOP stack on the seafloor is taken over by an assembly of control valves called a "Christmas tree" which is located on the platform deck. These valves can be used to vary the flow rate or to shut off the oil completely during an emergency.

Another common safety device is a "storm choke" which is set in the tubing string below the sea floor. Any unusual increase in the flow of oil from the well caused by fire or failure of surface equipment triggers this device to automatically close. Some types of subsurface safety devices use hydraulic pressure from the surface to keep them open. If pressure is lost, this type of device will close and choke off the flow of oil up the well.

When a well first goes into production, oil flow is usually facilitated by natural pressures. As production continues, this pressure begins to diminish, making the installation of an artificial lift necessary. This is usually accomplished by the use of gas. High pressure gas is injected down the drill hole from the surface through gas lift valves on the tubing. This gas mixes with the oil in the tubing, making a lighter mixture which is easier to lift. The existing formation pressure then becomes adequate to bring the oil to the surface.

Plate 2: Semisubmersibles can operate in relatively rough weather conditions due to their size and stability.

*(Photo by Don Tillapaugh)*

## 1.4 EXPLORATORY OFFSHORE RIGS

Exploratory rigs can drill up to five wells per year, depending on weather conditions. Essentially five types of platforms or "rigs" are used for this purpose: submersible platforms, jack-up platforms, semisubmersible platforms, drilling ships, and drilling barges. Submersible platforms are almost obsolete. They were used primarily for shallow water exploration and consisted of a platform supported by two large pontoons which were laid along the ocean floor for support. Jack-up rigs are used primarily for shallow water exploration. They have legs which extend to a depth of up to 122 m (400 feet). Once these legs are positioned securely on the bottom, the platform is jacked up to a safe level above the sea surface [usually 12 to 15 m (40-50 feet)]. Although very stable when in operation, they are subject to damage while the legs are being lowered, or during transit to other sites.

Semisubmersibles are used in areas where severe weather and operating conditions exist and although they can theoretically drill at almost any depth, they are more commonly used in waters around the 300 m mark.

These rigs are either self-propelled or towed by tugs to the site. They rest on huge submerged floats which keep them buoyant, and are kept in position by mooring lines and anchors weighing up to 15 tons. One of their main advantages is that they have the capability to operate in deep water in relatively rough weather conditions (i.e., 12 m seas and 50 knot winds).

Floating drill ships are generally used in waters which are greater than 300 m or in areas where quick manouver ability is required. These ships are either moored with anchors or kept in position by propellers activated by a dynamic positioning system. Drill barges are similar in operation to drill ships.

## 1.5 PRODUCTION RIGS

Unlike exploratory drilling, which is conducted from mobile drilling rigs, development drilling and production are usually carried out from fixed, bottom-placed platforms which can be classified as either steel or concrete. Steel-fixed piling platforms are made of steel and fixed to the seabed with huge steel pilings. The platform may be equipped to develop the field by drilling up to fifty wells from the same site or it may be equipped to handle production operations. This platform type may also include partial processing facilities to process various components of the well stream before shipment ashore.

Steel platforms currently being designed to operate in depths approaching 500 m (1,500 feet) consist of two types. The tender type, used primarily in shallow waters, requires a drilling tender vessel to be along-side it during operation. This vessel supplies all the facilities necessary to support the drilling phase (living quarters, storage, mechanical components, etc.).

Self-contained steel platforms are used in deeper waters and can withstand rough sea conditions. They include all components necessary for day-to-day operation and require support only for crew changes and restocking of supplies. In some cases, development drilling, production, and partial processing can occur simultaneously from a single, self-contained platform.

Concrete platforms are constructed of concrete and held to the bottom by ballast and their own weight. There is little difference between steel and concrete gravity platforms other than the material from which they are fabricated. Concrete platforms have certain advantages over other platform types if severe environmental conditions must be met. For example:

- If high winds or rough seas are common, the installation time for concrete platforms is much shorter than that for steel platforms
- If submarine troughs or trenches inhibit the installation of marine pipelines the concrete platform can be designed to include built-in storage capacity
- If the seabed does not readily lend itself to the driving of pilings, concrete gravity platforms may be the only alternative
- Since the platform is built vertically it can be constructed in a sheltered coastal area and floated out during good weather

Most concrete platforms are self-contained and can handle a variety of operations (e.g., development drilling, partial processing).

The disadvantage of concrete platforms is that the risk of fracture is high, since they weigh nearly 25,000 tons. Also, detailed studies of the sea bottom profile must be conducted before construction begins to ensure their correct placement.

## 1.6 SERVICE BASES

### 1.6.1 TEMPORARY SERVICE BASES

These bases form the links between onshore and offshore activities during the exploration phase. Their specific location is one of the first decisions to be made. The primary activity of these bases is to transfer materials and workers between the shore and offshore operations. Supply boats, crew boats and helicopters operate from the base on a 24-hour basis, 7 days a week. The first priority of these bases is to ensure maximum efficiency of time needed for a boat to unload and reload before returning to the offshore site.

These service base operations are usually quite small and the land they occupy is leased on a short term basis. Facilities include berthage for supply and crew boats, dock space, warehouse and open storage areas, a helipad, and space for supervisory and communications personnel.

### 1.6.2 PERMANENT SERVICE BASES

Permanent bases serve the same function as temporary bases differing only in size and intensity of activity. These bases supply essentially the same materials and services as needed during exploratory drilling but in much larger quantity. They permit development drilling to proceed smoothly by ensuring that enough material is on hand to allow up to 50 wells to be drilled from one platform. Services and facilities required include:

- Storage facilities for oil, fuel supplies and fresh water supply
- Space for fixed silos of cement and mud chemicals at the wharves for direct and quick loading by hose manifolds
- Storage space for tubulars for direct loading onto supply boats. The tubular goods are casing, drill pipe, tubing, and drill collars -all generally 12 m (40 feet) long with varying diameters. All have to be stacked separately and be readily accessible
- Warehousing to contain all the equipment which comes from a variety of suppliers

- Cranes - the normal crane is 25 tons with a working radius of 12 to 15 m (40-50 feet). Also, fork lift trucks, pole trailers, tractors for handling and stacking of materials. Equipment is usually preslung and prepacked
- General engineering facilities for servicing the rig and the equipment on board--spare parts, valves, pipe fittings
- Clothing
- Catering supplies
- Diving services
- Non-destructive testing services
- Specialist services stocking and servicing the many sites needed
- Engineering fabrication of special items
- Painting and cleaning services
- Pollution control, safety and fire-fighting equipment
- Transportation services
- Telex/Telecommunications
- Office accommodation and services
- Medical facilities
- Technical training facilities

### 1.6.3 BASES SUPPORTING PLATFORM AND PIPELINE INSTALLATION

Numerous vessels must be utilized for the installation of marine pipelines or production platforms (Plate 3). Companies involved in constructing these facilities usually set up their own service bases to support the crews and vessels involved. These bases require waterfront warehouse space and service/maintenance facilities for various vessels and barges. One such supply base can support several platform or pipeline installation operations at once.

## 1.7 REPAIR AND MAINTENANCE YARDS

These yards consist of many firms of varying capabilities which provide services to the operators of vessels and equipment involved in offshore oil and gas production. Their primary objective is the fast and efficient repair of all equipment used in the development of offshore fields.

Since many repair and maintenance activities occur underwater, specialized diving support vessels with onboard repair workshops are needed in addition to those located onshore.

## 1.8 PETROLEUM TRANSPORTATION FACILITIES

There are two main methods of transport used to move the product from the production site to shore: marine pipelines and tankers (or barges). Marine pipelines consist of a pressure source, gathering lines, intermediate

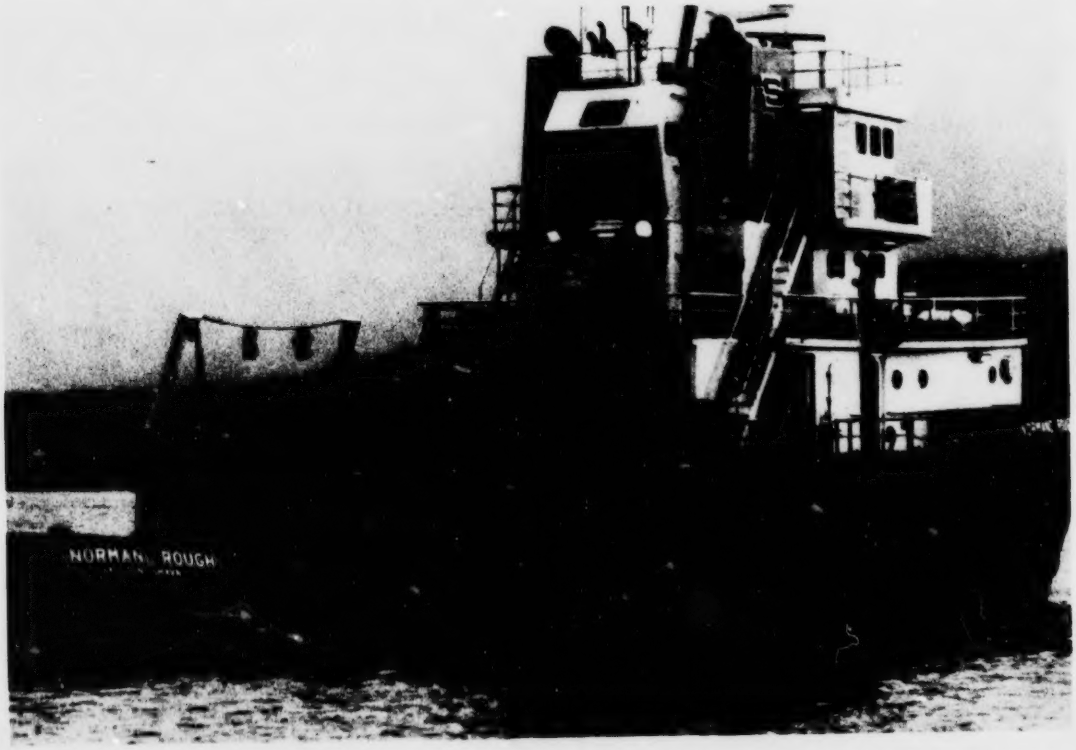


Plate 3: Drilling support vessels are important for the transfer of materials and supplies to offshore drilling rigs.

*(Petro-Canada photo)*

pressure boosting facilities (if necessary), and a landfall site. In general, companies prefer to construct pipelines for transport; however, since they are extremely expensive they tend to make them as short as possible.

### 1.8.1 TANKERS AND BARGES

A tanker or barge transportation system consists of offshore storage and loading facilities, tankers or barges, and a marine terminal. Offshore storage facilities are of three basic types: ocean bottom standing systems, floating systems, and above water storage systems. Ocean bottom facilities are steel or concrete storage units which are fixed to the bottom and extend above the water line where processing and loading equipment is located (concrete production platforms often have built-in loading and storage facilities). Floating storage systems are usually converted tankers and barges or other types of specially fabricated storage structures. Above water storage usually consists of large, typical oil storage tanks mounted on steel platforms. Marine terminals consist of berths for tankers or barges, crude oil tanks, ballast water treatment facilities, and miscellaneous harbour facilities.

In some cases a mixed system is used. Oil and gas is piped from an offshore platform to a marine terminal for shipment to other regions via tankers.

### 1.8.2 MARINE PIPELINES AND LANDFALL SITES

Pipelines are used to transport oil and gas from offshore production to onshore processing facilities. Pipelines are safer and more dependable than tankers and are usually more economical if large volumes of gas and oil are to be transported. Installation requires: 1) the use of a lay barge, 2) one to three tug boats, 3) several pipe supply vessels, and 4) bury barges if the line is to be covered.

The pipeline may originate from one platform, or several platforms connected by a network of smaller diameter pipes. Sometimes the formation pressure is high enough to drive the oil or gas ashore by itself. Usually however, pumps are needed for oil and compressors are required for gas. Both pumps and compressors are located on offshore platforms.

Gathering lines are small-diameter pipelines which gather oil and gas from several platforms or fields for transport to shore via a single, large-diameter pipeline. This is the pipeline through which most of the oil and gas which is collected from various platforms flows ashore. (All the gathering lines terminate at the head of this pipeline.) Pipe diameter depends on the production rate of the field, the desired operative pressure, and the bottom conditions of the route to be followed.

To maintain the correct operating pressures along the marine pipeline intermediate booster stations may be required. The need for their use depends upon: 1) the length of the pipeline, 2) the diameter of the pipeline, 3) the characteristics of the fluid being transported (i.e., viscosity, specific gravity, and whether liquid and vapor phases are to flow together), and 4) bottom characteristics of the site such as slope, topography, and depth along the route. Current technology has required all intermediate pumping stations to be located above water (usually on gravity type platforms) however, submerged pumping stations may become a reality in the future.

A landfall is the point at which the marine pipeline comes ashore. Depending on the fluid being transported and its ultimate destination, additional facilities such as gas plants, refineries, etc., may be located near this site. Oil pumping stations and storage facilities may also be located near the landfall area, especially if it is to be transported some distance via overland pipelines. If the oil is to be shipped via tankers, a marine terminal and storage tanks would be developed near the landfall site.

### 1.8.3 MARINE TERMINALS

Marine terminals are necessary whenever crude oil shipments are to be made over water by tankers or barges. They consist primarily of berthing capacity for vessels, loading and unloading equipment, storage tanks, terminal control and safety equipment, and harbour and navigation facilities.

Marine terminals can receive crude oil from marine pipelines or tankers which is destined for delivery to nearby refineries and can also receive refined petroleum products from tankers and store them for overland delivery to markets.

#### 1.8.3.1 Crude Pipeline/Tanker Terminals

These are terminals designed to load crude oil (received by pipeline) onto tankers. Usually, partial processing plants which separate brine, gas, and oil from the crude will be located offshore on the production platform. If, however, the crude comes untreated from the production platforms it usually contains gas and impurities which must be separated. If large amounts of L.P.G. (liquefiable petroleum gas) are present, they will be separated from the oil at a terminal site where gas processing facilities are located. The partially treated crude oil is then stored in large tanks prior to transport. Tankers arriving at the terminal are usually full of water which they use as ballast. This water is pumped out of the tankers as oil is being loaded and is stored ashore in ballast storage tanks. It is then treated by oil and water separators and by flocculation equipment.

#### 1.8.3.2 Crude Oil Receiving Terminals

These terminals are designed to provide crude oil to refineries. Tankers unloading at these sites pump crude oil into a surge tank farm where it is stored until being piped to refineries. Since tankers arriving at the terminal are usually full of oil, ballast treatment facilities are not required. These terminals will also contain bunker fuel (fuel used by the tanker itself) which is pumped onboard before the tanker departs.

### 1.8.3.3 Deep Water Terminals

Terminals of this type are usually much larger than the crude oil receiving terminals and are constructed to accommodate large supertankers with deep drafts. They are built primarily offshore in depths up to 33 m (100 feet) and consist of either a fixed sea island pier or a floating mooring system. Cargo is transferred to a tank farm which acts as a surge unit, then into the overland pipeline. This allows for quick unloading of the tanker and a slower but steadier operation of the pipeline.

### 1.8.3.4 Product Terminal

These terminals are designed to receive boat shipments of petroleum products from refineries. Since these shipments are usually made in smaller vessels the draft requirements for product terminals are much less than that required for crude terminals. Because each petroleum product is stored separately, product terminals usually require a greater number of small storage tanks than crude terminals.

### 1.8.3.5 Berthing Facilities

There are three main types of berthing facilities found at marine terminals: shore side fixed piers, offshore fixed piers, and offshore floating moorings.

#### A) Shoreside Fixed Piers

These piers are normally located inside a harbour, either perpendicular or parallel to the shorline, depending on: 1) current patterns within the harbor, 2) availability of land, 3) width of the harbour, 4) availability of tugs, and 5) prevailing wind direction. Such a pier is connected to shore via a trestle, and mooring is possible on one side of the pier only.

#### B) Sea Island Piers

These are fixed structures similar to shoreside fixed piers but are oriented to the most favourable wind, wave, and current direction and accessible to water craft only. Mooring is available on both sides of the pier.

C) Floating Moorings

These consist of an anchored floating buoy, floating hoses to connect the tanker manifold to the buoy, and undersea hoses which eventually lead up to the tank storage farm. Mooring is possible through all 360° surrounding this facility.

## 1.9 PARTIAL PROCESSING FACILITIES

These facilities are usually located on the offshore platform. They are designed to remove impurities from a crude oil well stream which consists of a mix of crude oil, natural gas, and formation water (brine water in the form of an oil-water emulsion in addition to dissolved and suspended solids). The natural gas is removed at the platform site and either burned (flared) or handled separately since it is usually too costly to pipe natural gas and oil together through the same pipe line (due to the friction involved).

Partial processing removes free and emulsified water, dissolved solids, and suspended solids down to the 1% level. Once the crude is partially processed it is delivered to a refinery for final processing. Shore based partial processing plants may be located separately or in conjuction with marine terminals and/or gas processing facilities.

## 1.10 GAS PROCESSING AND TREATMENT PLANTS

Gas processing plants are designed to remove valuable liquefiable hydrocarbons (missed by the normal separation methods) from the raw gas stream before it enters the main gas pipeline. Gas treatment plants are designed to remove all impurities from the gas. Either one of these facilities may house treatment, recovery and fractionation equipment used to separate recovered hydrocarbons into their various components. These plants are specifically designed for each gas stream they process and usually handle anywhere from $5.66 \times 10^4$ $m^3$/day to $5.66 \times 10^7$ $m^3$/day ($2 \times 10^6$ $ft^3$/day to $2 \times 10^9$ $ft^3$/day), with a life expectancy of 10 to 20 years.

## 1.11 REFINERIES

Refineries consist of a number of units designed to produce a variety of products by physically and chemically altering all or part of the crude oil stream. The complexity of the plant depends upon the type of crude being refined and the number of products desired.

Refineries are highly automated. When the crude enters the production line it may undergo up to four distinct processes (separation, conversion, treatment and blending) to produce the desired mix of products. In separation, the crude is distilled into light, intermediate, and heavy hydrocarbons. Conversion chemically alters the various hydrocarbon groups into more refined groups. Treatment converts or removes undesirable components (i.e., hydrogen sulfide and mercaptans), and blending is used to mix various base stocks to produce a more diverse final product. After refining, the products are stored for future distribution.

In addition to the actual processing units, this facility includes storage tanks, influent and effluent water treatment facilities, ancillary buildings and service (administration buildings, machine shop, storage and warehouse space, electrical substations, firehouse, pumping stations, truck loading terminals, etc.), transport action systems (roads, pipelines, railroads, parking lots), and a buffer zone.

## 1.12 PETROCHEMICAL PLANTS

These are facilities which produce chemicals derived from petroleum sources, including natural gas, natural gas liquids and products of oil refineries. Petrochemicals differ from other petroleum products in two main respects: 1) they exist as relatively pure compounds (rather than mixtures of several different compounds), and 2) they are used as chemicals instead of fuels.

Because of the complexity involved in processing a large variety of products there is no standard size for petrochemical plants. Plants are designed according to the needs and market position of the company building them and may occupy as few as 0.8 to 1.2 ha (2 or 3 acres) to as many as several hundred or even thousands of hectares.

## 1.13 PLATFORM FABRICATION YARDS

These yards are large industrial construction areas where the platforms used to drill for and produce offshore oil and gas are fabricated. There are two principal types of fabrication yard: steel and concrete.

### 1.13.1 STEEL FABRICATION YARDS

These yards consist of large, cleared areas which have most of their facilities set back from the waterfront. However, actual construction of the steel platforms is done as close to the waterfront as possible to facilitate launching.

The main body of a steel platform is the jacket which is constructed at or near the waterfront. The jacket consists almost entirely of tubular steel members welded together. Once complete, it is rolled on dollies or rails onto a launch barge and towed to the installation site.

Once the jacket is on site, it is upended and slowly sunk to the ocean floor. It is then pinned to the bottom using huge steel pilings. The deck section of the platform is then lifted on top of the jacket and secured. The individual deck components (drilling rig, living quarters, operation facilities, helipad, and other modular components) are then attached. This signals completion of the platform. The various aforementioned modular units may be constructed on site or may be contracted out to other, entirely separate facilities.

### 1.13.2 CEMENT FABRICATION YARDS

Cement fabrication yards also occupy large, open, waterfront sites. Here, however, the platforms are built in large, deeply dredged dry dock basins, separated from very deep adjacent water by a coffer dam. When the platform is completed, the coffer dam is opened and the dry dock floods, causing the platform to float.

The construction and assembly of concrete gravity platforms differs greatly from that employed for steel fixed piling platforms. The base of the concrete platform is composed of many cylindrical pre-stressed concrete cells and is constructed vertically in the dry dock to a height ranging from 9 to 24 m (30 to 80 feet). Some of the cells may be used for ballast water, while others may be used for crude oil storage (an important feature not found in steel fixed piling platforms). When the base is complete (approximately 9 months), it is floated out of dry dock to sheltered waters, 46 to 90 m deep (150 to 300 feet). Its ballasts are then filled and the base section is partly submerged to permit further vertical construction and/or completion.

If the platform is to be used in shallow water, the deck section is simply attached to the base and the appropriate drilling, operation, storage and living quarters modules are placed onboard.

If the platform is to be used in very deep water, huge concrete pillars or towers sometimes as high as 90 m (300 feet), are constructed on top the partially submerged base section. This procedure can take from 9 to 15 months to complete.

When complete, the platform is towed to the installation site and placed on the sea floor. Concrete is filled in around the base to ensure a solid footing. While the entire construction process can take up to two years, installation of the platform generally takes only a few days.

## 1.14 PIPELINE COATING YARDS

In these yards flexible steel pipe is prepared for underwater use through the application of concrete and asphalt sealers. Each pipe is usually coated with a primer, an anti-corrosion coat, and three inches of concrete. These coatings are necessary to overcome flotation and to prevent corrosion. A permanent yard usually occupies 40 to 60 ha (100-150 acres) of waterfront land and employs roughly 200 people. Construction of the yard and coating plant can be accomplished within 6-8 months using a relatively small labor force. The yard requires approximately 230 m (750 feet) of harbor frontage and the channel depth at the pier must be at least 5 metres. Access to truck and rail transportation is also essential. A portable yard (railroad operation) may be built on 12.14 hectares (30 acres) of land and takes approximately 3 months to construct. The yard can produce coated pipe in a single season.

## 1.15 ANCILLARY INDUSTRIES

Oil companies are responsible for exploring and producing oil and gas and typically contract with other firms for many of the specific operation, equipment, supplies, and services necessary during the operation. These small industries gather near ports, producing large-scale local impacts. They generate jobs, tax revenues, business opportunities, and increased cash flow in the area. Conversely, they place increased demand on waterfront land, port facilities, and public services.

Generally, these ancillary industries can be divided into 3 main categories of business:

A) Business directly related to oil and gas development - this would include those companies involved in supplying mud, cement, drilling tools and equipment, wellhead equipment, fishing and rental tools, logging and perforating equipment, helicopters, catering, diving services, completion and production services, and inspection and testing equipment.

B) Multi-industry related businesses - these are businesses which service the oil and gas industry but are also involved in supplying other businesses. Examples include repair and maintenance yards, trucking and stocking firms, fabrication, machine shops and welding services, labor contractors, and oil spill recovery services.

C) Non-oil and gas related businesses - this is the second group of firms which are needed but are not specifically oil and gas related. Such firms include office supply firms, crane and lift equipment and services, fuel and lubricant companies, communication facilities, and other miscellaneous supply firms.

A brief description of the major industries listed above in category "A" follows.

### 1.15.1 DRILLING FLUID COMPANIES

These companies provide drilling fluids (muds) and engineering services to drilling contractors. Drilling fluids are complex mixtures of clay, weighting agents, and chemical additives in water. During drilling, this fluid is circulated through the drill hole to: 1) cool and lubricate the drill bit, 2) transport drill cuttings to the surface, and 3) control formation pressure (thereby preventing oil and gas from flowing up and out of the well). Specific muds can be mixed to suit each specific well.

### 1.15.2 CEMENT COMPANIES

These companies provide highly specialized cementing services. They provide cementing materials, bulk cement and additives, and blend them in the proper proportions for each specific well. These companies also own and operate the machinery on the rigs which mixes the cement with water and pumps the slurry down the drill hole.

At times cement must be pumped down the hole in order to seal casings in the hole and to separate various formations encountered. Because of the high temperatures and pressures involved, only specific cements are utilized. By the use of certain additives the rate at which the cement hardens can be altered to meet the conditions of each specific well.

### 1.15.3 DRILLING TOOLS AND EQUIPMENT COMPANIES

These companies manufacture and sell the tools and equipment required during the drilling process. These include rock bits, reamers, hole openers, drill collars, and numerous other items. Some of this equipment is expendable and some becomes a permanent part of the drilling rig.

### 1.15.4 WELLHEAD EQUIPMENT COMPANIES

These companies provide the surface equipment which controls oil and gas wells during drilling and production. This equipment includes such items as blowout preventer stacks, drilling chokes, and mud manifold systems.

## 1.16 DISTRICT OFFICES

These are facilities set up by an oil company to house its technical and administrative personnel who are responsible for supervising and coordinating exploration, construction, and production activities pertaining to offshore oil and gas development. The district office is responsible for:

1. designing drilling programes for wells
2. designing mud, casing, and cement programs for well development
3. designing onshore and offshore facilities
4. coordinating construction of equipment and facilities
5. supervising development drilling
6. supervising and coordinating production operations

The size of the district office is ultimately determined by the size and composition of the hydrocarbon field.

## 1.17 LAND PIPELINE SYSTEMS

Pipelines are common systems used to transport hydrocarbons from one onshore facility to another. There are 3 types of pipeline systems which may be used:

A) Crude oil pipeline - if crude oil is brought ashore by marine pipelines or by tanker, it may undergo partial processing in plants usually located near the landfall sites or marine terminals and then be transported via overland pipelines to one or more refineries. A typical pipeline is 1 m (36") in diameter with the pipe walls made of steel from 9.53 mm to 15.88 mm (0.375" and 0.625") thick. The pipeline is coated with coal tar enamel and wrapped with bitumen glass fiber. Mainline valves are usually located at 16 km (10 mile) intervals with pump stations located at various positions along the route.

B) Petroleum product pipelines - carry refined products (such as gasoline, fuel oils, etc.) or liquefied petroleum gas (L.P.G.) from the refineries to various markets. These pipelines are usually quite complex with many branch pipelines receiving products from a number of refineries or gas plants. The various products are sent through a pipeline in "batches". Each batch is piped through the line in a definite sequence to minimize mixing and contamination of the various products. Some of the larger pipelines gather products from up to 10 sources and distribute them to as many as 281 marketing terminals. One hundred and twenty different products and grades of products can be moved through the system with a turnover time of approximately 10 days.

C) Natural gas pipeline systems - once offshore natural gas is brought ashore it may be processed by a gas plant near the landfall site and transported in a pipeline system to utility companies. These lines, many several hundreds of kilometres long, have compressors located at intervals every 80 to 112 km (50-70 miles). These compressor stations help maintain adequate pressure within the system.

## 1.18 SUMMARY

Offshore oil exploration and production is a complex operation involving a multitude of events which must be carefully and accurately coordinated. It involves four distinct phases: exploration, development, production, and shutdown. A time period of 15 to 40 years is usually required between the initial stages of exploration and the final steps in abandonment.

If the commercial viability of an oil or gas field is considered negligible, development will not proceed past the exploratory phase. On the other hand, if large quantities of oil and gas are found and the economic situation is favourable, a commitment to full scale development may occur. Once this decision has been made, numerous facilities must be constructed simultaneously with production drilling to ensure a smooth and uninterrupted flow of oil to the market place. This may mean the construction of marine pipelines and/or the enlargement of new or existing port facilities to accommodate increased tanker traffic. In addition, refineries, petrochemical plants, gas processing complexes, and overland pipelines may also be essential to the development of a find, and work on their construction may commence. These are just a few of the major developmental projects which may occur. Thus, in order to accurately predict the environmental impacts of developing the offshore oil and gas fields of British Columbia a thorough and comprehensive knowledge of all four phases of development must be obtained (See Figure 1.1 for reference map of British Columbia).

## 1.19 DISCLAIMER

None of the information contained in this chapter is original. It has been condensed and rewritten from numerous references, the major of which were: 1) New England River Basins Commission (1976 , Factbook, Onshore Facilities Related to Offshore Oil and Gas Development; 2) Fenco Consultants Ltd. (1979), Sources of Pollution and Causes of Environmental Disturbance Associated with Canadian Offshore Oil and Gas Production; 3) Commonwealth of Massachusetts (1976), Offshore Oil Development, Implications for Massachusetts Communities.

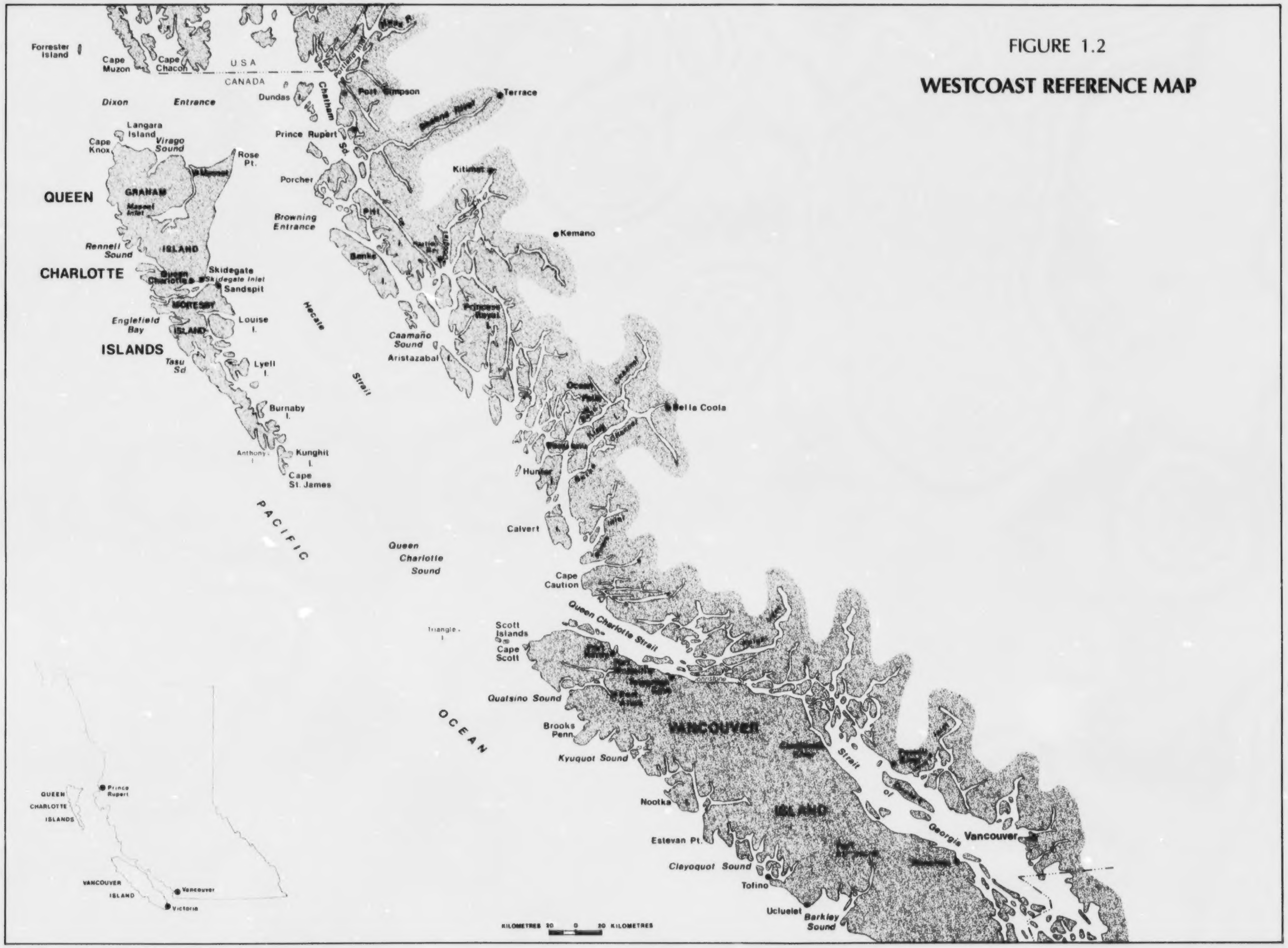


FIGURE 1.2

**WESTCOAST REFERENCE MAP**

Forrester Island
Cape Muzon
Cape Chacon
U.S.A.
CANADA
Dixon Entrance
Dundas
Chatham Sd
Port Simpson
Terrace
Skeena River
Prince Rupert
Langara Island
Cape Knox
Virago Sound
Rose Pt.
Porcher
Kitimat
QUEEN
GRAHAM
Masset Inlet
Browning Entrance
Pitt I.
Kemano
Rennell Sound
ISLAND
CHARLOTTE
Banks
Skidegate
Queen Charlotte
Skidegate Inlet
Sandspit
MORESBY
Englefield Bay
ISLAND
Louise I.
Hecate
Princess Royal
Caamaño Sound
Aristazabal I.
ISLANDS
Tasu Sd
Lyell I.
Strait
Bella Coola
Burnaby I.
Anthony I.
Kunghit I.
Cape St. James
Hunter
PACIFIC
Calvert
Queen Charlotte Sound
Cape Caution
Queen Charlotte Strait
Triangle I.
Scott Islands
Cape Scott
Quatsino Sound
OCEAN
Brooks Penn.
VANCOUVER
Kyuquot Sound
Strait of Georgia
Nootka
ISLAND
Vancouver
Estevan Pt.
Clayoquot Sound
Tofino
Ucluelet
Barkley Sound
KILOMETRES 30 0 30 KILOMETRES
QUEEN CHARLOTTE ISLANDS
Prince Rupert
VANCOUVER ISLAND
Vancouver
Victoria

# CHAPTER 2

# OFFSHORE PHYSICAL ENVIRONMENT

Jim Slater

# CHAPTER 2—OFFSHORE PHYSICAL ENVIRONMENT

## 2.1 INTRODUCTION—THE PHYSICAL SETTING

This chapter describes the coastal marine environments likely to be affected by the different phases of offshore petroleum exploration and development in British Columbia. The area of reference has been divided into nine sub-areas (Table 2.1), with emphasis on the North Coast, (i.e., that part of the British Columbia coast bounded to the north by the Alaska Border and to the south by the north end of Vancouver Island). The North Coast encompasses five major bodies of water: Dixon Entrance, Hecate Strait, Queen Charlotte Sound, Chatham Sound, and the west coast of the Queen Charlotte Islands. These areas are defined by Crean (1967), and Fisheries and Environment Canada, (1978), and are represented in Figure 2.1. Queen Charlotte Strait will also be included in the discussion to follow.

The information in this chapter has been organized into three general categories as follows:

i) a description of the physical and chemical parameters of the study area and their relevance to offshore oil
ii) the identification of the adequacy of existing information
iii) a discussion of information gaps for each parameter

### 2.1.1 DIXON ENTRANCE

Averaging 50 km in width, Dixon Entrance is bounded to the north by the Alaska Border and to the south by the north coast of Graham Island. It continues eastward from Rose Point to the north tip of Stephens Island. To the west, it is bounded by the northwestern tip of Langara Island and Cape Muzon. The western entrance is divided into a North and South channel by Learmonth Bank, a broad, shallow bank rising to within 35 m of the surface. To the east, Dixon Entrance is bounded by Chatham Sound.

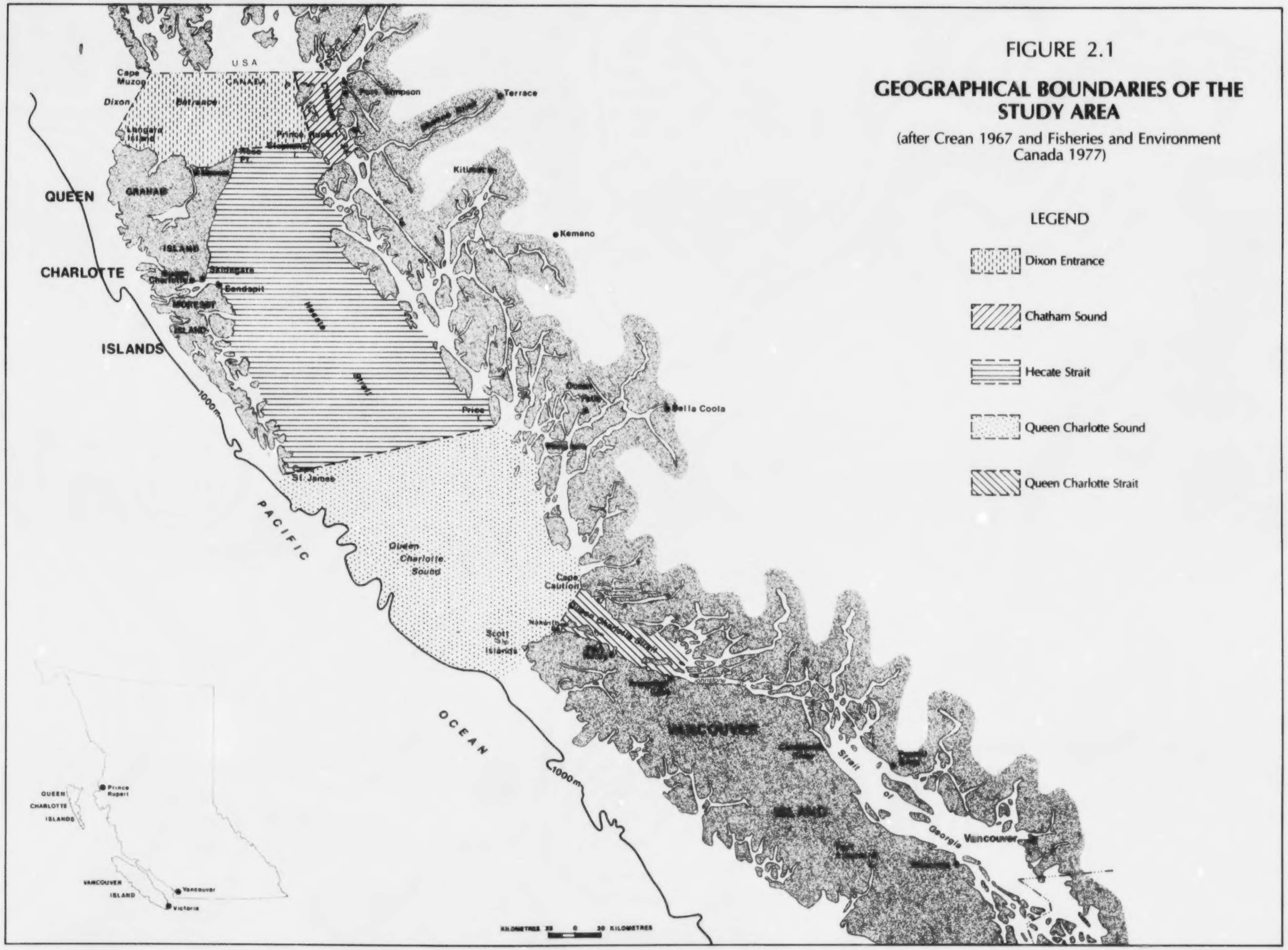


FIGURE 2.1

GEOGRAPHICAL BOUNDARIES OF THE STUDY AREA

(after Crean 1967 and Fisheries and Environment Canada 1977)

LEGEND
▨ Dixon Entrance
▨ Chatham Sound
☰ Hecate Strait
░ Queen Charlotte Sound
▧ Queen Charlotte Strait
U S A
CANADA
Cape Muzon
Dixon
Entrance
Langara Island
Port Simpson
Terrace
Prince Rupert
Stephens I.
Rose Pt.
Kitimat
Kemano
QUEEN
CHARLOTTE
ISLANDS
GRAHAM
ISLAND
MORESBY
ISLAND
Skidegate
Sandspit
Hecate
Strait
Price I.
Ocean Falls
Bella Coola
Cape St. James
1000m
PACIFIC
OCEAN
Queen Charlotte Sound
Cape Caution
Scott Islands
VANCOUVER
ISLAND
Strait of Georgia
Vancouver
KILOMETRES 30 0 30 KILOMETRES
QUEEN CHARLOTTE ISLANDS
Prince Rupert
VANCOUVER ISLAND
Vancouver
Victoria

### 2.1.2 HECATE STRAIT

This strait separates the outlying islands of mainland British Columbia from the Queen Charlotte Islands. It is bounded to the north by Dixon Entrance and to the south by Cape St. James and the southern tip of Price Island. The southern entrance is about 140 km wide, but narrows to about 48 km where it meets Dixon Entrance.

### 2.1.3 QUEEN CHARLOTTE SOUND AND QUEEN CHARLOTTE STRAIT

Queen Charlotte Sound adjoins the southern end of Hecate Strait and covers an area from the mainland coast of British Columbia to approximately the 1,000 metre contour line. It is bounded to the south by the northern tip of Vancouver Island and the entrance to Queen Charlotte Strait between Nahwitti Bar and Cape Caution.

Queen Charlotte Strait separates northern Vancouver Island from the mainland of British Columbia and extends from the southeast perimeter of Queen Charlotte Sound to a group of islands north of Telegraph Cove.

## 2.2 PHYSICAL AND CHEMICAL PARAMETERS

### 2.2.1 GEOGRAPHY & BATHYMETRY

#### 2.2.1.1 Geography, Geology, and Tectonic History

An adequate knowledge of the geography of the study area is needed to determine the routine and non-routine onshore impacts of offshore oil exploration and development. In order to determine the oil retention potential (see Section 2.2.6.1) for a particular area, the following characteristics of coastal geography will need to be identified:

a) High- and low-energy wave environments (open coast, inland waters)
b) Locally sheltered areas (embayments, inlets, estuaries)
c) Slope of shoreline (flat, gradual, steep)

d) Type of substrate (bedrock, cobble, sand, mud)

The above listed parameters and their effects on oil retention potential (ORP) are discussed further in Section 2.2.9.1.

Unless otherwise indicated, the following material on the geography and geology of the North Coast is based on Yorath (pers. comm. 1982) and Sutherland Brown (1968).

The geology of British Columbia is among the most varied and complex in the world. Much of this complexity is reflected in miniature by the Queen Charlotte Islands. In plan, this group forms a scimitar-shaped wedge which, together with Vancouver Island, belong to a tectonic plate of mesozoic origin (230-63 million years ago). This plate began its migration northward

Plate 4: Embayments such as this pocket beach are sensitive environments because of their low rates of seaward sediment transport (Lepas Bay, northwest coast of Graham I.).

*(Photo by Mits Naga)*

from the southern hemisphere about 140 million years ago (m.y.). Sometime between 40 and 90 m.y., it made contact with the North American plate and gradually developed into the coastline we are familiar with today.

Basically, the Queen Charlotte group can be divided into 3 major physiographic units:

1) The Queen Charlotte Lowlands, which comprise the northeastern half of Graham Island, consist mostly of low-lying Quaternary material formed over the last million years. Most of the lowland is below 150 m with much of the terrain characterized by muskeg, although elevations may reach 370 m. Shorelines are regular, and shore processes are intensive and dynamic, particularly in the area of Rose Spit, where progradation rates are on the order of 0.3 to 0.4 m/yr. (Harper, 1980).
2) The Skidegate Plateau can be thought of as a broad strip of terrain which is oriented southeast to northwest. A few deep fjords on its east and west coasts typify much of its coastal geography. The plateau consists mainly of Jurassic volcanic (180-135 m.y.) and Cretaceous sedimentary (135-63 m.y.) sequences overlain by erosional post-Eocene (<36 m.y.) material. Heights on the Skidegate Plateau are moderate, averaging 640 m.
3) The Queen Charlotte Ranges comprise most of Moresby Island, with the exception of a peninsula on the northeastern tip of the island, and include the southeastern tip of Graham Island. The seaward coast is an abrupt, straight-line scarp related to the Queen Charlotte fault. Peaks here are over 1100 m. The mountainous, drowned coastline of the east coast of the Queen Charlotte Ranges, characterized by local pocket beaches of sand and gravel, contrasts sharply with the regular, low-lying eastern coast along the plateau and lowland areas.

The exposed Pacific coasts of the Queen Charlottes and Vancouver Island are very high wave-energy environments. They are typically fjord-like with many islands and low, rocky shorelines on the outer fringes. In general, the west coast of the Queen Charlottes has a much steeper profile than that of Vancouver Island. On the west coast of Vancouver Island, a few isolated but extensive (10 km) beaches have developed on the exposed coast at Long Beach, Wickaninnish Bay and Florencia Bay. The complex system of islands and inlets in Barkley Sound provides many low-energy areas sheltered from the force of the open ocean.

The continental shelf is the zone adjacent to the continent which extends from the low water line to a depth where there is a marked increase in slope, and is usually defined by the 200 m contour line. It is either nonexistent or extremely narrow (less than 5 km) off Moresby Island, but widens from 44 km at the south entrance to Juan de Fuca Strait to a maximum of 100 km off southern Vancouver Island.

The Hecate Depression is a broad submarine basin between the mainland and the Queen Charlottes extending in a southeast to northwest direction. It is flanked by the Coast Mountains on the mainland, which rise to a height of 2800 m, and by the Queen Charlotte Ranges to the west. Parts of the coast bordering directly on Hecate Strait are flat coastal plains fronting a high fjord-like coast. These are known as "strandflats".

On the outer islands of the mainland coast (e.g., Banks Island) the western shorelines are rocky and low-lying with many rock islets and islands. Similarly, some portions of the east coast of the Queen Charlottes are characterized by a low, rocky outer coastline.

In general, the Hecate Strait - Queen Charlotte Sound region is dominated by two major shoreline environments:

A) low-lying, high wave-energy rocky outer shorelines
B) steep-sided, low-energy inland channels and fjords

A large depositional range is undergoing considerable marine erosion on the north and southeast coasts of Graham Island. The east coast is primarily one of erosion and transportation, with cliffs up to 20 m high at Cape Ball. Sediments are being transported to the northeast by littoral drift towards Rose Spit, and westward along the north coast towards Masset Sound. Along this drift sector, there is a noticeable decrease in particle size from south to north. Beaches on the north shore of Graham Island are as wide as 150 m at low tide and are backed by dunes in some sections, as are the beaches along the northeast coast between Rose Point and Cape Ball. East-facing beaches are generally narrower, steeper, and coarser than those facing north.

The only major irregularities along the north coast of Graham Island are Virago Sound and Masset Inlet (see Figure 1.1). Virago Sound leads into Naden Harbour, which is characterized by mud flats up to 6 km wide at low tide and extensive marshes in the backshore. The head of Masset Inlet has a fjord-like coast, but is actually more like a small inland sea which feeds into Masset Sound through a long, narrow channel that winds its way 30 km to the waters of Dixon Entrance.

#### 2.2.1.2 Bathymetry

Detailed knowledge of bathymetry (depths, bottom contours, slopes, etc.) is critical to the safe location and operation of offshore facilities. Surveys will also be necessary in locating areas subject to the mass movement of sediments, unstable slopes, active faulting, or gaseous sediments.

The deepest part of Dixon Entrance (350-400 m) occurs at its western and northern perimeters (Figure 2.2). The bottom slope gradually increases until it reaches a sill south of Cape Chacon (270 m) and a shallow basin (100-150 m) west of Dundas Island.

Chatham Sound is essentially an extended estuary fed by the Skeena River to the south, and by the Nass River to the north. It is separated from Dixon Entrance by a submarine ridge which supports a chain of shoals and islands. At its northern end this ridge is broken by a deep, irregular

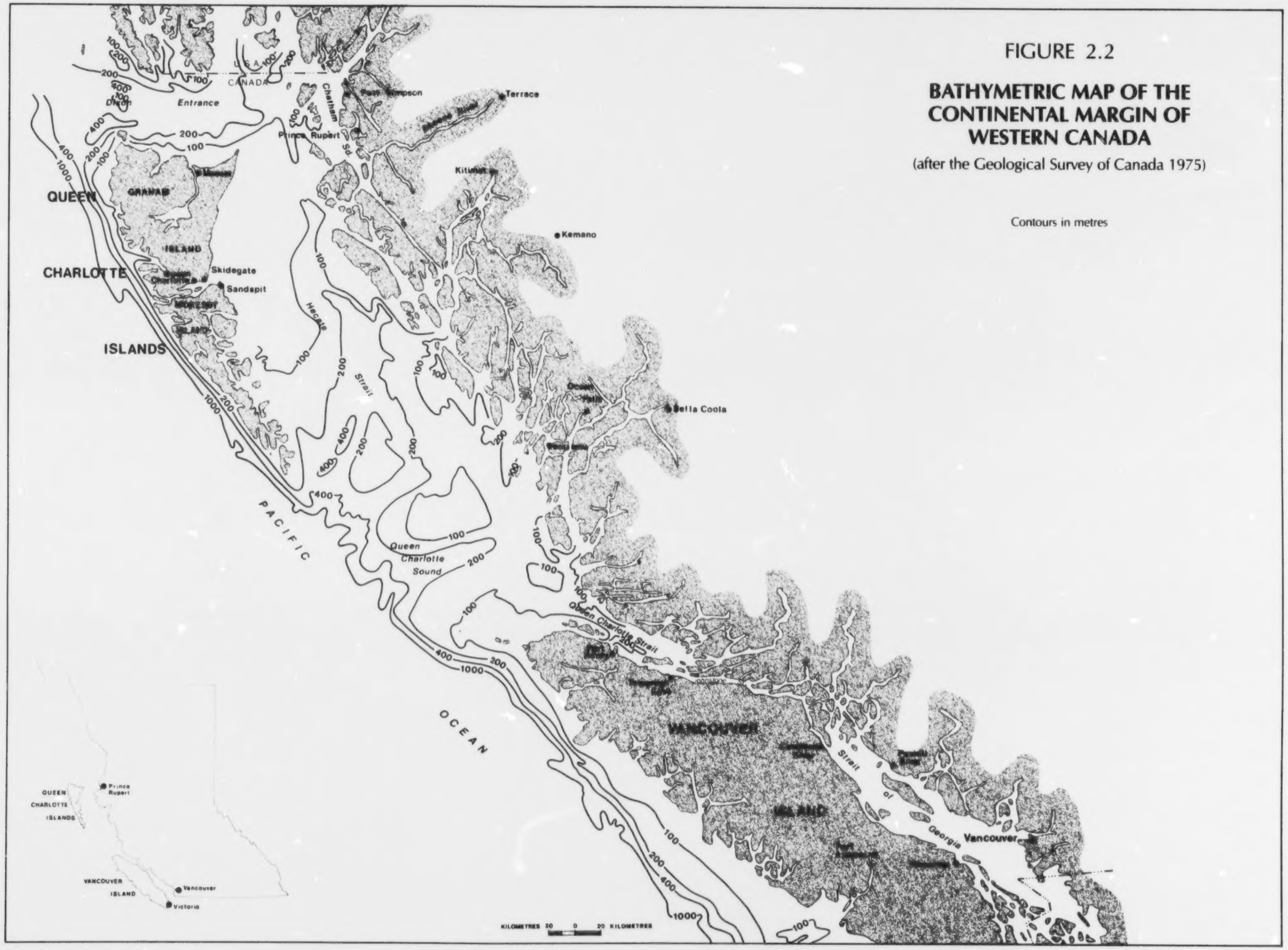

U.S.A.
CANADA
Dixon
Entrance
Chatham Sd.
Prince Rupert
Port Simpson
Terrace
Kitimat
Kemano
QUEEN
CHARLOTTE
ISLANDS
GRAHAM
ISLAND
Skidegate
Sandspit
MORESBY
ISLAND
Hecate
Strait
Bella Coola
Queen Charlotte Sound
Queen Charlotte Strait
PACIFIC
OCEAN
VANCOUVER
ISLAND
Strait of Georgia
Vancouver
100
200
400
1000
KILOMETRES 20 0 20 KILOMETRES
QUEEN CHARLOTTE ISLANDS
Prince Rupert
VANCOUVER ISLAND
Vancouver
Victoria

FIGURE 2.2

**BATHYMETRIC MAP OF THE CONTINENTAL MARGIN OF WESTERN CANADA**

(after the Geological Survey of Canada 1975)

Contours in metres

channel which extends westward to join Clarence Strait. Average sill depth here is about 170 m.

The southern end of Hecate Strait averages 185 m in depth. The northern end consists largely of a shallow bank approximately 50 m deep. The main shipping lane is a relatively deep (minimum depth 82 m) but narrow (3 km) channel which skirts the outlying islands of the mainland between Queen Charlotte Sound and Dixon Entrance.

Most of Queen Charlotte Sound is less than 250 m deep, with its central region characterized by a shallow bank 35-45 m in depth. North and south of this bank, depths exceed 180 m (McDonald et al., 1980).

#### 2.2.1.3 Hydrocarbon Potential

In the late 1960's, Shell Oil drilled 14 exploratory wells in Hecate Strait, Queen Charlotte Sound, and off the west coast of Vancouver Island. Of these wells, two sites (Prometheus and Pluto) drilled southwest of Barkley Sound exhibited gas shows in the shallow zone, while one site (Sockeye) in Hecate Strait exhibited an oil show as staining in the sidewall core. Another well in Hecate Strait (Murrelet) penetrated potential oil-bearing sediments (see Figure 5.1), but no oil was found.

The relative lack of success in finding oil-bearing sediments has been attributed to the fact that the models then being used in exploration were not based on the theory of plate tectonics (Yorath, pers. comm., 1982). The origin of sedimentary basins is much better understood now than it was when Shell was drilling its exploratory wells.

Based on one theory (Yorath, pers. comm., 1982), about 17 million years ago the continental margin of North America drifted over a "hotspot" in the earth's mantle, resulting in rift formation and the subsidence of the area presently known as Queen Charlotte Sound. As a result, much of Queen Charlotte Sound and Hecate Strait were formed from non-marine sediments.

Given the length of time and temperatures involved, it is thought that conditions were right in the rift basin for the maturation of organic material and the subsequent formation of gas and oil deposits.

Tertiary sediments in northern Hecate strait are thought to be gas-prone, whereas the tertiary rifts southeast of Moresby Island and in Queen Charlotte Sound are considered oil-prone. The latter includes the Khungha formation, a limestone and shale feature that forms part of the Wrangellia Terrain, a tectonic plate of Mezosoic origin which merged with the North American plate in upper Cretaceous or lower Tertiary times (Section 2.2.2.1).

Conservative estimates for hydrocarbon finds off the British Columbia coast approximate 9 trillion cubic feet for natural gas and 250 million barrels for oil reserves. This is based, in part, on similarities in geology and existing hydrocarbon finds in Cook Inlet, Alaska (Haimila and Procter, 1981).

### 2.2.2 CLIMATE

Climatic factors off the British Columbia coast can result in severe weather conditions (winds, waves, precipitation, and fog). These factors will undoubtedly have a major influence on the design criteria, location, and operating standards for both offshore and onshore facilities.

In winter, the Aleutian Low is well established over the Gulf of Alaska, and coastal winds prevail from southeast to southwest. Storms are frequent, characterized by considerable precipitation in the form of rain. Snow is common at the heads of inlets and at higher elevations. Most winter storms and weather systems come from the west, with winds from the southeast, followed by shorter periods of northwest winds. The incidence of fog is lowest at this time of year, with the main impediment to visibility being precipitation. The buildup of cold arctic air in the interior of British Columbia leads to strong northeasterly "squamish" winds blowing out of the mainland inlets.

Summer coastal winds are usually controlled by the North Pacific High off the coast which pushes further north and dominates summer weather patterns, bringing winds that prevail from the northwest. While there are fewer storms, the incidence of fog is highest at this time of year. Seas are generally rougher in fall and winter. Wave heights tend to be greater in northern waters, increasing with seaward distance for all months.

A complete listing of meteorological information is available in the Climatological Station Data Catalogue for British Columbia, published by Environment Canada.

#### 2.2.2.1 Winds

Regions of persistent, high-velocity winds (e.g., off the southern tip of Moresby Island - Figs. 2.3 and 2.4) pose relatively high risks to offshore facilities. Oil tankers in ballast are susceptible to high winds, particularly during nearshore navigation and docking procedures. Oil slick trajectories are also influenced by prevailing wind patterns. Wind direction and duration, wind speed, and visibility are critical factors for determining cleanup feasibility. On-site weather forecasting capabilities are also necessary to ensure that safe operating procedures are carried out on a day-to-day basis in order to minimize risks not only to the environment, but to crews living and working on offshore rigs and supply vessels.

The dominant winds of the North Coast, including Dixon Entrance, Hecate Strait and Queen Charlotte Sound, parallel the axis of the coastal mountain barriers which lie in a general southeast-to-northwest direction. On a micro-scale, winds are funneled by the valleys, fjords and channels of coastal areas.

For the west coast of Vancouver Island, the Vancouver Island Mountain Range, the Olympic Mountains and the West Coast Range exert a strong influence on wind flow patterns. In the winter months, prevailing winds are from the southeast, with wind speeds averaging 30-40 km/h. In summer the predominant wind patterns are westerly and northwesterly with average wind

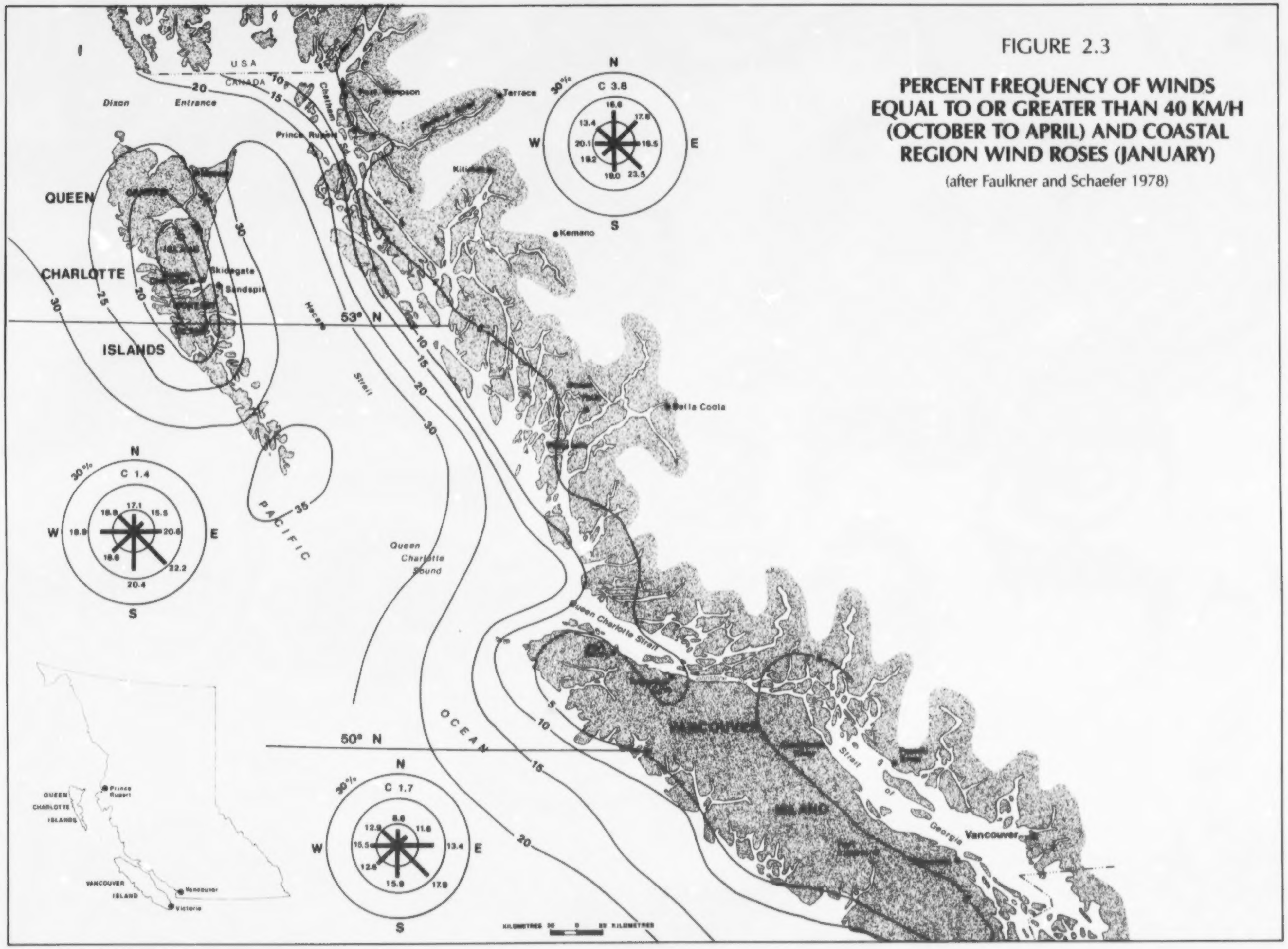

U.S.A.
CANADA
Dixon
Entrance
Prince Rupert
Port Simpson
Terrace
Kitimat
Kemano
Bella Coola
QUEEN
CHARLOTTE
ISLANDS
Skidegate
Sandspit
53° N
Hecate
Strait
PACIFIC
OCEAN
Queen
Charlotte
Sound
Queen Charlotte Strait
VANCOUVER
ISLAND
Strait of Georgia
Vancouver
50° N
10
15
20
25
30
35
5
N
S
E
W
30%
C 3.8
16.6
17.6
13.4
20.1
16.5
19.2
19.0
23.5
C 1.4
17.1
15.5
18.8
18.9
20.6
18.6
22.2
20.4
C 1.7
8.6
12.9
11.6
15.5
13.4
12.8
15.9
17.9
KILOMETRES 50 0 50 KILOMETRES
QUEEN CHARLOTTE ISLANDS
Prince Rupert
VANCOUVER ISLAND
Vancouver
Victoria

FIGURE 2.3

**PERCENT FREQUENCY OF WINDS EQUAL TO OR GREATER THAN 40 KM/H (OCTOBER TO APRIL) AND COASTAL REGION WIND ROSES (JANUARY)**

(after Faulkner and Schaefer 1978)

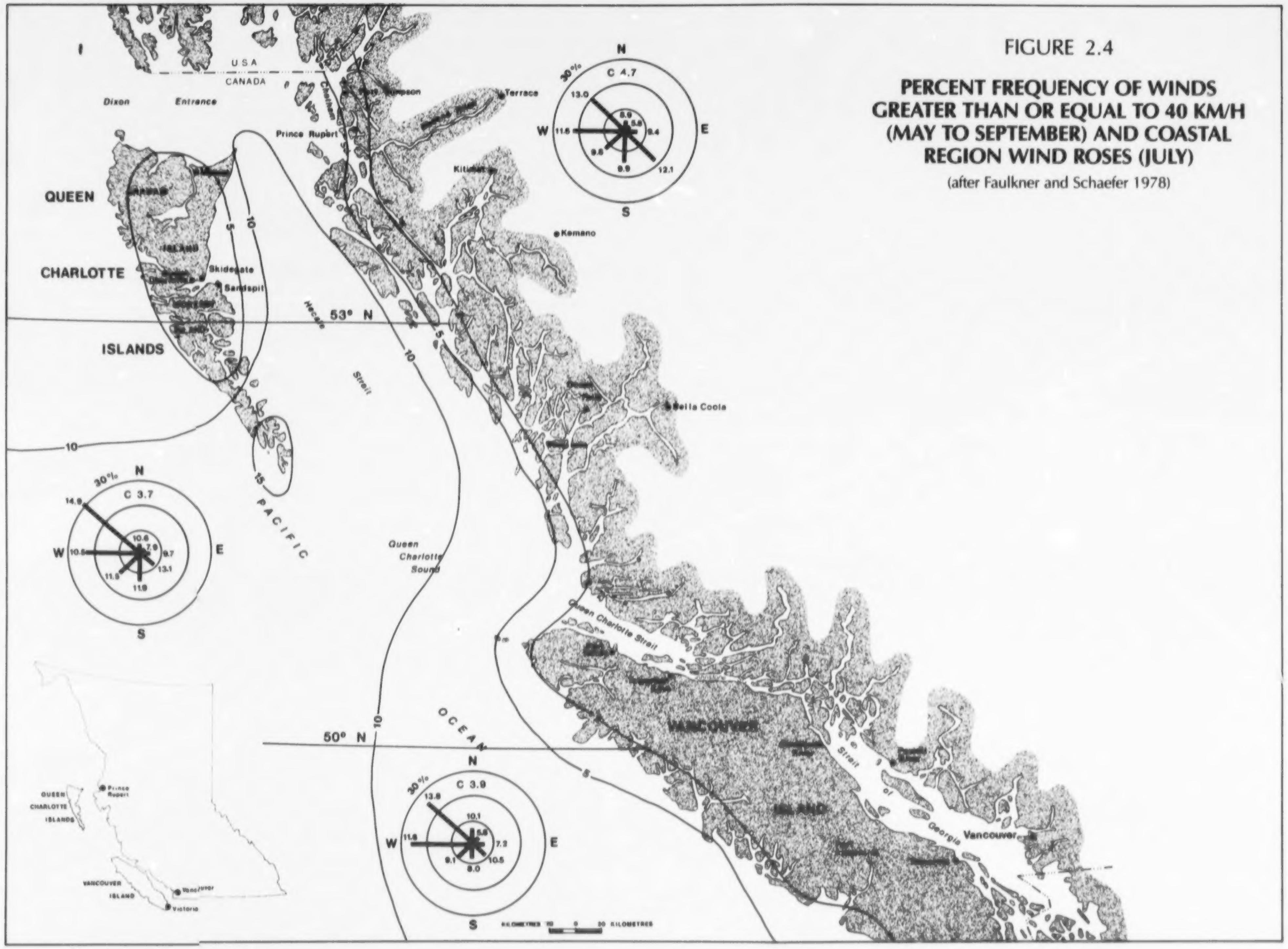

U.S.A.
CANADA
Dixon Entrance
Prince Rupert
Terrace
Kitimat
Kemano
QUEEN CHARLOTTE ISLANDS
Skidegate
Sandspit
53° N
Hecate Strait
Bella Coola
PACIFIC OCEAN
Queen Charlotte Sound
Queen Charlotte Strait
VANCOUVER ISLAND
Strait of Georgia
Vancouver
50° N
N
S
E
W
30%
C 4.7
C 3.7
C 3.9
10
5
15
KILOMETRES 20 0 20 KILOMETRES
Victoria

FIGURE 2.4

**PERCENT FREQUENCY OF WINDS GREATER THAN OR EQUAL TO 40 KM/H (MAY TO SEPTEMBER) AND COASTAL REGION WIND ROSES (JULY)**

(after Faulkner and Schaefer 1978)

speeds of 21.5 km/h and 25.6 km/h, respectively. Within 45 kilometres of the west coast of Vancouver Island, wind speeds greater than 40 km/h occur about 15% of the time in the winter and 5% in summer (McDonald et al., 1980).

For the exposed Pacific coasts of the Queen Charlottes, winter winds are similarly southeast, reaching their maximum in early winter. Prevailing summer winds are northwest in southerly areas, changing to southwest in northerly areas. Wind patterns are affected by local topography. Annual wind cycles can only be described for relatively large areas (see Figures 2.3 and 2.4).

While very little information is available for extreme wind conditions, gusts up to 145 km/h have been recorded for the Queen Charlotte Sound-Hecate Strait region.

Figures 2.3 and 2.4 give percentage patterns for winds exceeding 40 km/h on the British Columbia coast. It is reasonable to assume that similar patterns would exist for the frequency of higher wind velocities as well.

#### 2.2.2.2 Temperature and Precipitation

Extremely cold air temperatures hamper the efficiency of operations on rigs and platforms and increase the risk of human error. Snow, sleet, and rain affect visibility for tankers, supply vessels, and helicopters, which in turn increases the risk of accidents.

Temperature ranges throughout the study area are moderate, showing less than a 30°C difference between minimum and maximum extremes for the British Columbia north coast and a 38°C difference for the west coast of Vancouver Island. Monthly and annual mean and extreme temperatures, and monthly long-term average amounts of precipitation for coastal marine areas are summarized in Volumes II and X of the Summary of Synoptic Meteorological Observations (SSMO).

Average annual total precipitation for coastal areas is about 1500 mm, with rainfall heaviest in October, least in July. Extremes range from about 400 mm at the southern tip of Vancouver Island to over 8000 mm in the Barkley Sound area (Owens, 1977).

As well, oil slick degradation is marginally reduced by cold air temperatures and accelerated by freshwater lenses caused by precipitation and runoff.

### 2.2.2.3 Icing from Seaspray

The northern British Columbia coast, with its mild climate and relatively warm waters, is not an area where freezing spray is likely to occur. Minimum sea-surface temperatures of about 6°C are encountered near Dixon Entrance in late January. The coldest air temperatures coincide with invasions of polar air masses, high pressure conditions, and relatively light winds. Given the small number of days when these conditions prevail in coastal locations, icing of superstructures due to freezing spray would be a rare event.

## 2.2.3 WAVES AND CIRCULATION

Onshore facilities could be affected by waves (see 2.2.3.1 and 2.2.3.4). In addition, bottom-mounted offshore facilities (jack-up rigs, gravity platforms, and pipelines) are susceptible to current scouring and sea bed sediment transport. Drilling rigs, production platforms, tankers and supply vessels are susceptible to storm surges, storm-generated waves, ocean currents and tidal currents. Slick trajectories and oil degradation rates are also affected by storm surges, ocean currents, and tidal excursion.

The chief mechanisms affecting surface circulation are winds, tides, freshwater discharge, and large-scale oceanic currents. Winds associated with the Aleutian Low in autumn and winter and the North Pacific High in summer create semi-permanent pressure systems which are the major causes of seas and swells off the west coast of Vancouver Island. The term "sea" refers to waves caused by local winds. "Swell" refers to waves that have progressed beyond the influence of the winds that generated them.

The north coast of Graham Island is affected by Pacific swell waves entering through Dixon Entrance, while the east coast is affected by locally generated waves formed along the extensive and unimpeded axis of Hecate Strait. For the exposed Pacific coasts of the Queen Charlottes and Vancouver Island, locally generated waves exceed 3 m 8% of the time in summer and 20% of the time in winter. Swell waves exceed 2 m 10% of the time in summer and 30% in winter (Owens, 1977).

The Pacific Coast Pilot gives considerably more severe conditions for swells. West of Cape St. James, recorded swells are greater than 3.65 m

Plate 5: Southeast winds blowing up the long axis of Queen Charlotte Sound and Hecate Strait can produce storm-generated waves of considerable proportions.

*(Mobil Oil photo)*

40% of the time from January through March. In fact, the largest wave ever recorded off the coast of British Columbia was observed from the drilling rig SEDCO 135 anchored near Cape St. James on October 22, 1968, when gusting winds in excess of 145 km/h generated a wave between 27 and 30 metres high (James, 1969).

The significance of storm-generated waves on offshore facilities cannot be underestimated, particularly in light of the fate of the drilling rig, "Ocean Ranger", which sank during a storm off the coast of Newfoundland on Feb. 15, 1982, resulting in the loss of 84 lives.

#### 2.2.3.1 Storm Surges

Storm surges are sea-level changes associated with the passage of storms and are the result of wind action and differences in atmospheric pressure. When superimposed on tides, they may cause extensive flooding on low-lying coasts, especially when they coincide with high spring tides. This in turn poses a potential threat to shore-based facilities, particularly those at the heads of inlets.

#### 2.2.3.2 Current Scouring

Current scouring is related to the movement of water near the sea bed as a result of storm activity. Studies have shown that a storm-related current scours can occur up to 2 m in depth. A single storm surge can scour up to half a metre of sediments (U.S. Dept. of the Interior, 1980). Since this type of phenomenon tends to undermine objects resting on the ocean bottom, it may prove to be a potential hazard for underwater pipelines.

#### 2.2.3.3 Sheet Flow (Sea Bed Sediment Transport)

Studies have shown that storm-generated mass movement of surface sheets of sea bed sediments is a possibility (Nelson, 1977). If impeded by solid objects, such movement can form a wedge of material 1-5 m thick, and can pose a relatively serious hazard to pipelines and onshore facilities.

#### 2.2.3.4 Tsunamis

Offshore facilities in open waters would probably not be affected by tsunamis, but associated shock waves travelling across the sea floor could cause damage to jack-up rigs, gravity platforms, and pipelines.

Shore-based facilities (discussed in Chapter 4) may be at risk in the event of flooding caused by tsunamis, or to the potential for large-scale spills of volatile or toxic chemicals and the subsidence of foundation materials, through the direct "shock" effects of a seismic event.

Tsunamis are very long oscillations of the sea surface generated by earthquakes, volcanic eruptions, or landslides. They may originate at any point along the seismically active rim of the Pacific. Recent large tsunamis observed on the British Columbia coast originated from the northern Pacific, the Tonga Islands, and Chile. Of these tsunamis, five caused significant damage in the period 1946-1964. The latest large tsunamis experienced on the British Columbia coast followed the 1964 Alaska earthquake and resulted in an observed wave height of 240 cm at Port Alberni at the head of Alberni Inlet on Vancouver Island. This same quake caused flooding of coastal areas in Rennell Sound on the west coast of Graham Island (K. Moore, pers. comm., 1982).

Tsunamis have periods ranging from 10-90 minutes and may propagate at speeds of 500 knots in the open ocean (McDonald et al., 1980). The individual wave crest takes the form of a slow rise in water level over a period of 10-15 minutes. Superimposed on this are ordinary wind waves, and tides. Tsunami waves break on the shore, producing a destructive surf, which, when coupled with resultant flooding, can cause extensive damage.

Tsunamis would not be felt by persons on a ship in the open sea because of their enormous length (100-200 km) and small height (0.3 to 0.6 m). It is only as the wave reaches shore that the water begins to pile up and coastal areas are inundated (Strahler, 1971).

### 2.2.3.5 Ocean Currents

The fate of any oil spill will be determined to a large extent by prevailing ocean currents in the spill area. Since currents are influenced by a number of variables such as winds, seasonal heating and cooling patterns, coastal geomorphology, and bathymetry, it is difficult to forecast the trajectory of even routine contaminant spillage without on-site, real time equipment. However, estimates can be made based on prevailing patterns, as shown in Figures 5.2 and 5.3.

The principal ocean current influencing the B.C. coast is the counter-clockwise-flowing Alaskan gyre. In winter it flows north along the coast from about 40°N latitude. In summer, it turns north at about 45°N latitude so that the west coast of Vancouver Island is more influenced by the weak, variable and south-flowing California current. Both currents, however, are easily masked by the effects of localized storms and strong winds. In general, surface movement off Vancouver Island is dominated by slow eddies and meanders.

In winter, persistent southeast winds produce a northward flow along the long fetch of Hecate Strait up to its northern boundary. This flow continues seaward through Dixon Entrance, along the north shore of Graham Island and then northward along the Alaskan coast. In spring and early summer, southwest winds subside and freshwater discharges from the Nass and Skeena Rivers reach their annual maximum. Northerly currents decrease and an estuarine structure is established in northern Hecate Strait and Dixon Entrance. The lower salinity surface layer flushes to the north in Hecate Strait and then seaward through Dixon Entrance (see Figures 2.5 and 2.6).

Southern Chatham Sound is essentially a large estuary with a fresh water layer moving northward (due to winds and the Coriolis effect), with a relatively small amount escaping through Brown Passage. The Nass River discharges into north Chatham Sound through Portland Inlet. The water mixes with the Skeena's discharge, resulting in a net northwesterly movement into Dixon Entrance. Under heavy Nass River discharges, Nass waters can effectively block Skeena River water from moving north beyond Tugwell Island.

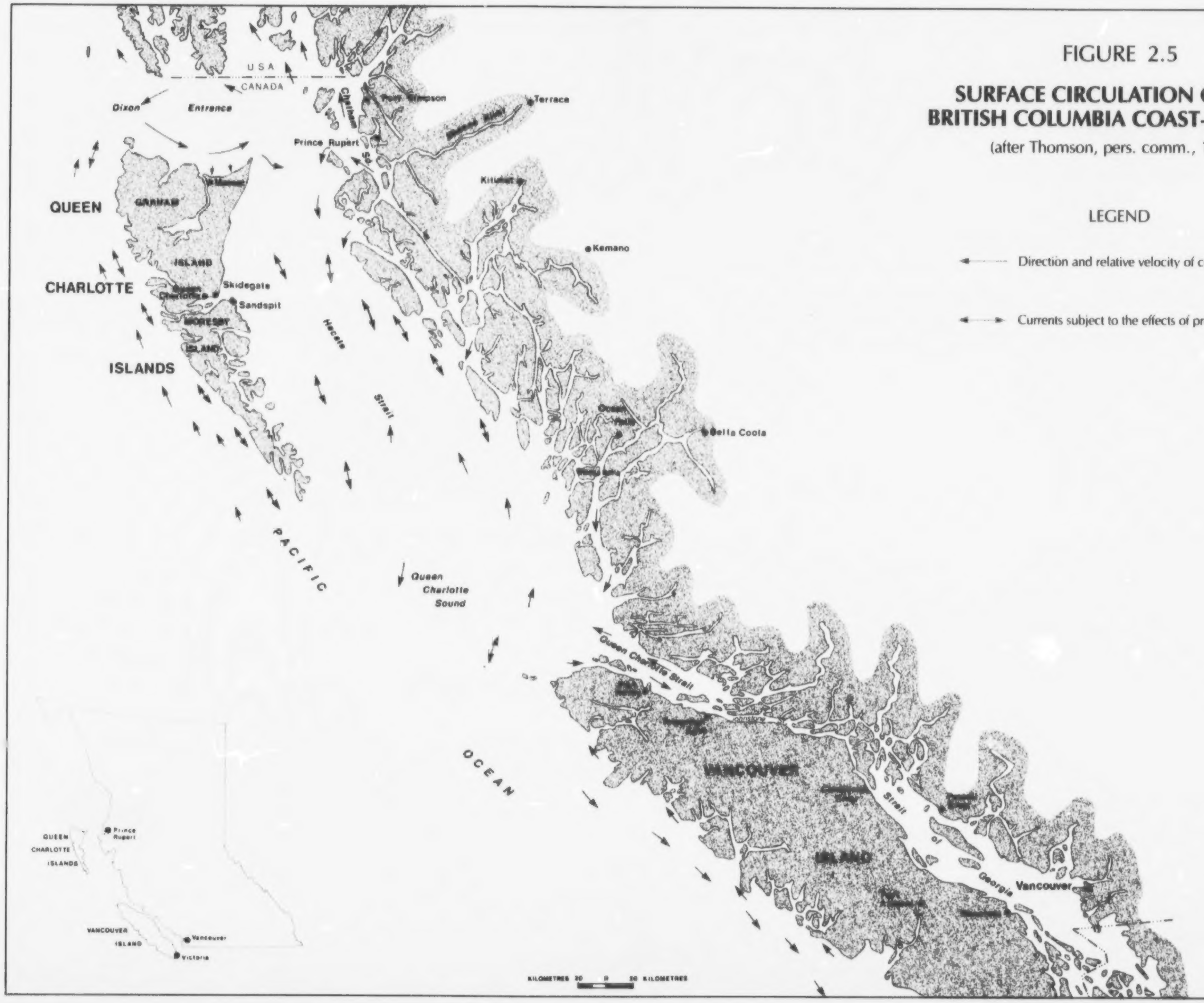

U S A
CANADA
Dixon
Entrance
Port Simpson
Terrace
Prince Rupert
Kitimat
Kemano
QUEEN
CHARLOTTE
ISLANDS
GRAHAM
ISLAND
Skidegate
Sandspit
MORESBY
ISLAND
Hecate
Strait
Bella Coola
PACIFIC
OCEAN
Queen
Charlotte
Sound
Queen Charlotte Strait
VANCOUVER
ISLAND
Strait
of
Georgia
Vancouver
QUEEN
CHARLOTTE
ISLANDS
Prince
Rupert
VANCOUVER
ISLAND
Vancouver
Victoria
KILOMETRES 20 0 20 KILOMETRES

FIGURE 2.5

SURFACE CIRCULATION OFF THE BRITISH COLUMBIA COAST—SUMMER

(after Thomson, pers. comm., 1981)

LEGEND

| | |
|---|---|
| ←······ | Direction and relative velocity of current |
| ←······→ | Currents subject to the effects of prevailing winds |

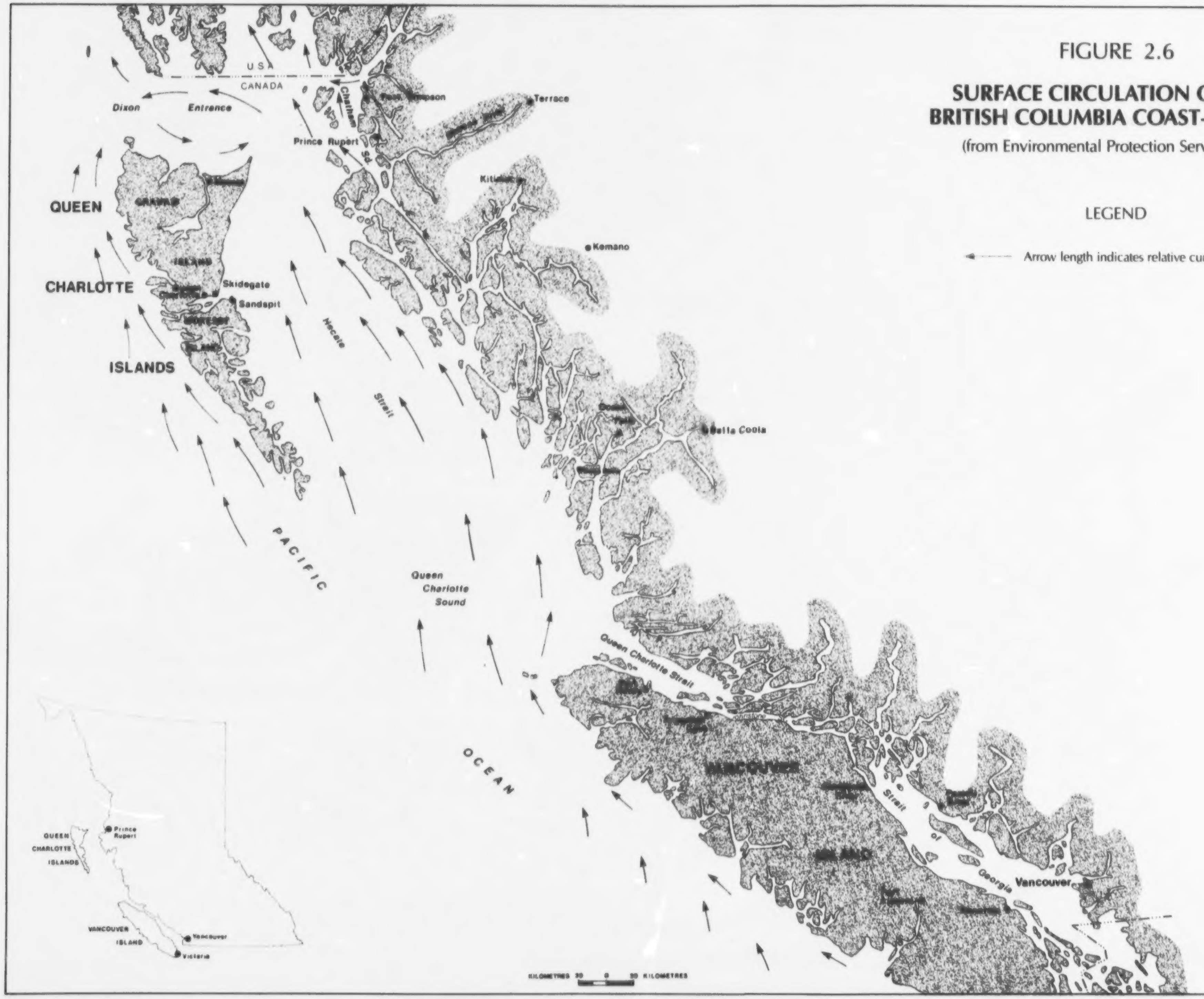

U.S.A.
CANADA
Dixon
Entrance
Chatham Sd.
Port Simpson
Prince Rupert
Terrace
Kitimat
Kemano
QUEEN
CHARLOTTE
ISLANDS
Skidegate
Sandspit
Hecate
Strait
Bella Coola
PACIFIC
OCEAN
Queen
Charlotte
Sound
Queen Charlotte Strait
VANCOUVER
ISLAND
Strait
of
Georgia
Vancouver
QUEEN
CHARLOTTE
ISLANDS
Prince
Rupert
VANCOUVER
ISLAND
Vancouver
Victoria
KILOMETRES 20 0 20 KILOMETRES

FIGURE 2.6

SURFACE CIRCULATION OFF THE BRITISH COLUMBIA COAST—WINTER

(from Environmental Protection Service 1978)

LEGEND

← Arrow length indicates relative current velocity

Below the surface waters of northern Hecate Strait and Dixon Entrance, a reverse intrusion of cool saline water moves landward. Despite this process, westerly winds can develop in Dixon Entrance and result in a net eastward flow at all depths.

Little is known about circulation patterns off the west coast of the Queen Charlottes. Measurements taken from the Bowie Seamount (200 km off the coast) indicate a net easterly surface movement. Upwelling may occur in summer owing to northwesterly winds which give rise to a weak, narrow current to the southwest, immediately adjacent to the coast. However, this pattern can be overridden by local topography and weather conditions.

Transport away from the Vancouver Island west coast is considerably greater than it is off the Queen Charlottes, so that the effect of a south-flowing current in summer is probably similarly increased by the effects of northwest winds. Southeast winter winds, or perhaps a continuation of the Davidson Current, result in a convergence of oceanic waters off Vancouver Island, and consequently, in a net northwestward surface drift. Upwelling off the west coast, induced by northwest winds in the summer, may occur to depths of 200-300 m (Freeland and Denman, 1982).

In summary: during winter, surface and deeper flows over the continental slope and shelf are almost always poleward. A northeast shoreward component prevails in the upper layer over the inner shelf, while in deeper water there is a net offshore flow (downwelling). The longshore current at 20 m depth can exceed 50 cm/sec although it is usually about 20-25 cm/sec in winter. The amplitude of the longshore component decreases with depth from mid-shelf to outer shelf. Few periods of southward flow are recorded. In summer, oceanic circulation (the Alaskan gyre) shifts northward, and coastal winds shift from southeast to northwest. Surface flow throughout the first 100 m of the water column tends southward at about 10 cm/sec along the eastern border of Hecate Strait. Eddies and meanders are more evident, and currents are more variable nearer to the shore, but mean poleward flows persist and upwelling occurs regularly. Currents vary from less than 5 cm/sec in the open ocean to a maximum of 8 m/sec at Nakwato Rapids (separating Seymour Inlet north of Vancouver Island from Queen Charlotte Sound).

### 2.2.3.6 Upwelling and Downwelling

Upwelling is a significant process because it brings oxygen-poor, nutrient-rich waters to coastal areas and inlet systems. This process may play an important part in the weathering and movement of slicks, but more significantly, upwelling areas may be associated with high primary productivity. This in turn may be associated with concentrations of fish and pelagic birds (Brown, pers. comm., 1982). If these correlations can be shown to exist, then identified areas of upwelling would require special attention when locating offshore facilities and operations.

Upwelling is the intrusion of water from moderate depths (200-500 m) toward the sea surface. In British Columbia coastal areas, upwelling is associated with longshore winds blowing from the northwest (Fig. 2.8). The effect of this upwelling is the net transport of surface water seaward. To replace this surface water, cold, saline water is entrained from the halocline and "wells up" along the coast. However, since prevailing winds in British Columbia coastal areas are from the southeast, downwelling is the more common occurrence (Fig. 2.7). In this process, surface waters move shoreward, and bottom waters are driven offshore.

### 2.2.3.7 Tides

Tidal circulation serves to increase lateral spread and possibly vertical mixing of oil in the water column due to current-induced turbulence.

The incursion of oil into estuaries such as the Nass and Skeena River systems and sea arms such as the Masset Sound due to tidal circulation is a distinct possibility if an oil spill occurs. The resultant risk is contamination to sensitive estuarine and salt marsh environments. This risk is increased when it is combined with the effects of strong diurnal onshore sea breezes produced by the summer heating of coastal land masses.

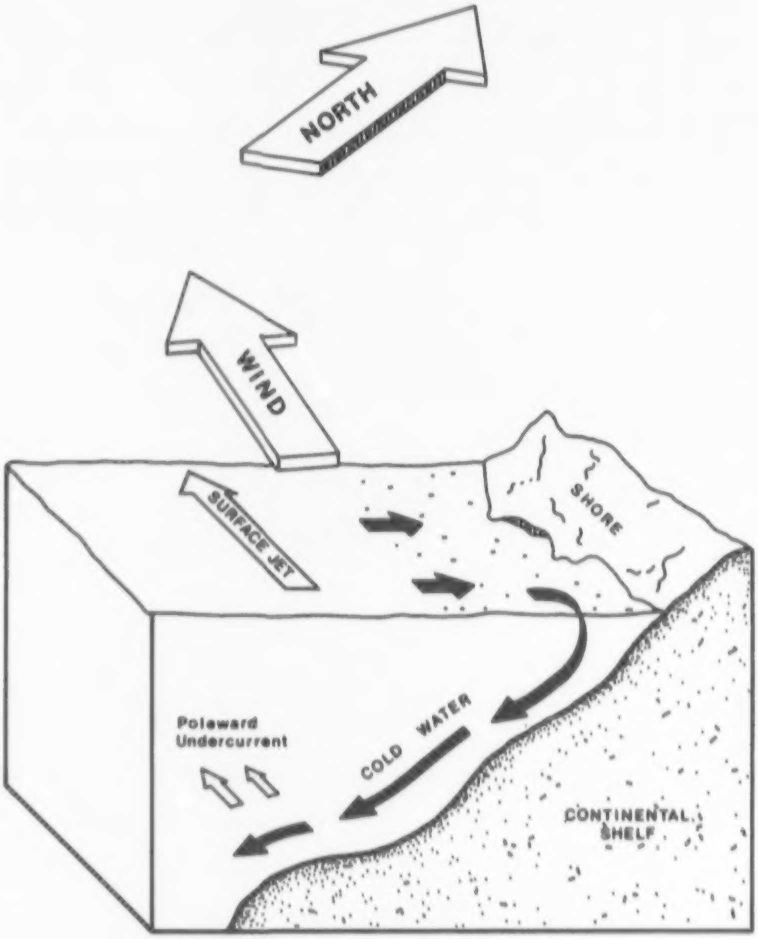

NORTH
WIND
SURFACE JET
SHORE
Poleward
Undercurrent
COLD WATER
CONTINENTAL
SHELF

FIGURE 2.7

**A SCHEMATIC DIAGRAM OF THE DOWNWELLING PROCESS OFF THE COAST OF VANCOUVER ISLAND**

(after Trans Mountain 1980)

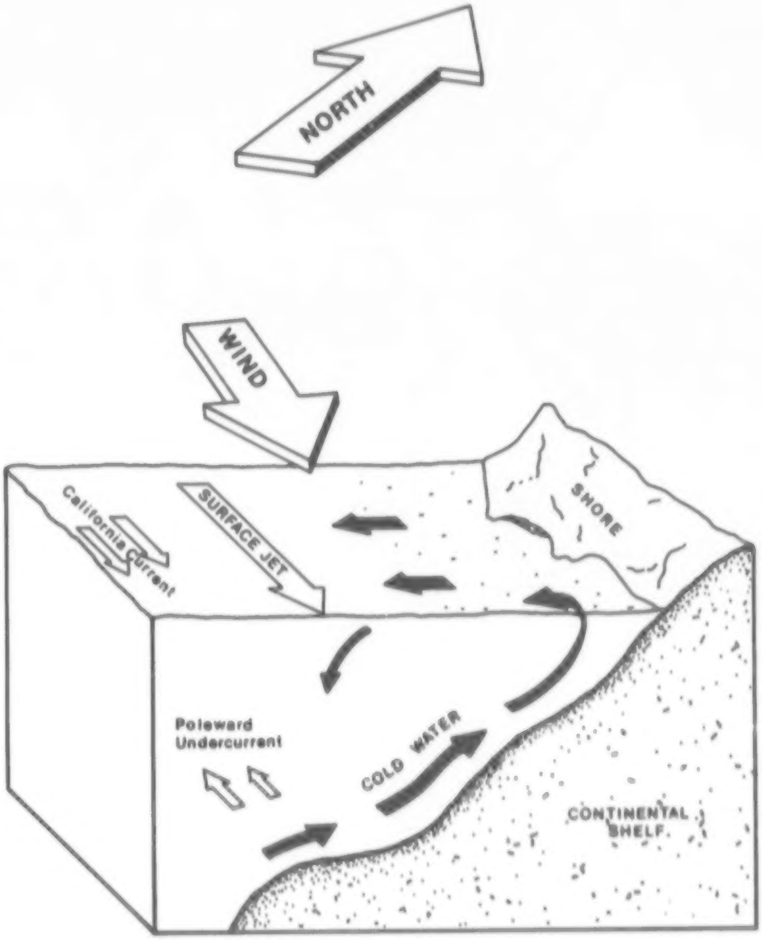

NORTH
WIND
SHORE
California Current
SURFACE JET
Poleward Undercurrent
COLD WATER
CONTINENTAL SHELF

FIGURE 2.8

**A SCHEMATIC DIAGRAM OF THE UPWELLING PROCESS OFF THE COAST OF VANCOUVER ISLAND**

(after Trans Mountain 1980)

Tides for the North Coast are both diurnal (one day between high tides) and semi-diurnal (one-half day between high tides). The incoming (flood) tide first arrives at the North Coast at the western entrance to Queen Charlotte Sound and reaches the western end of Dixon Entrance about 50 minutes later (Fig. 2.9). The tide propogates north up the west coast of the Queen Charlottes and then east through Dixon Entrance. The two branches of the flood tide meet near the north end of Hecate Strait about one hour after their initial arrival in Queen Charlotte Sound. In Hecate Strait, the meeting of tides occurs 40-50 km further north in summer than in winter. The combined tides swing west across Hecate Strait, reaching the south-eastern shores of Graham Island about 15 minutes later. The diurnal range for the Queen Charlottes varies from about 3 m in the south to about 5 m in the north.

A counterclockwise cyclonic vortex is set up in Dixon Entrance by the meeting of tides from Dixon Entance and Queen Charlotte Sound in northern Hecate Strait. However, a light wind and the effects of runoff can suppress the characteristics of this gyre completely.

From May to October, the net near-surface movements west of Queen Charlotte Sound and southern Hecate Strait are northwest. Tidal currents in central Queen Charlotte Sound are mostly rotary, showing no preferred direction.

Tidal currents are evident in Chatham Sound and the Skeena Estuary, where current speeds can exceed 4 knots. A classic salt wedge pattern is demonstrated here: saline water is entrained shoreward as the freshwater surface layer moves seaward.

In the northern Inside Passage between the North Coast and Vancouver Island, tidal mixing is intense and the water column tends towards homogeneity. In Queen Charlotte Strait, an upper, less saline layer is formed from local runoff and mixed water from Johnstone Strait. Beneath this layer is one which intrudes from Queen Charlotte Sound. Tidal currents generally decrease with depth (Thomson 1981; Thomson and Nuggett 1980).

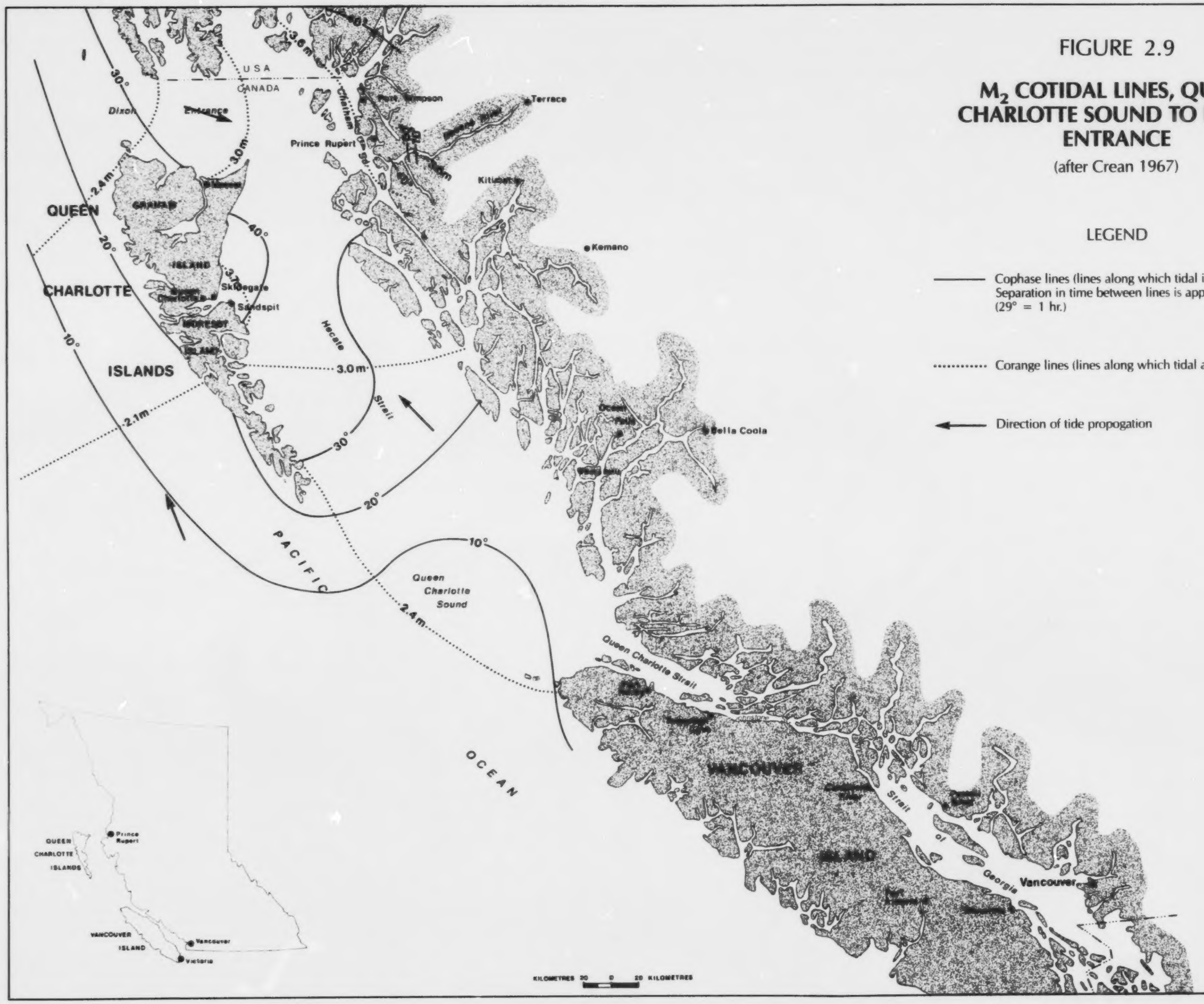

USA
CANADA
Dixon Entrance
Prince Rupert
Port Simpson
Terrace
Kitimat
Kemano
QUEEN CHARLOTTE ISLANDS
GRAHAM ISLAND
MORESBY ISLAND
Skidegate
Sandspit
Queen Charlotte
Hecate Strait
Bella Coola
Ocean Falls
PACIFIC OCEAN
Queen Charlotte Sound
Queen Charlotte Strait
VANCOUVER ISLAND
Strait of Georgia
Vancouver
30°
20°
10°
40°
3.6m
3.0m
2.4m
2.1m
3.7
KILOMETRES 20 0 20 KILOMETRES
QUEEN CHARLOTTE ISLANDS
Prince Rupert
VANCOUVER ISLAND
Vancouver
Victoria

FIGURE 2.9

**M$_2$ COTIDAL LINES, QUEEN CHARLOTTE SOUND TO DIXON ENTRANCE**

(after Crean 1967)

LEGEND

——— Cophase lines (lines along which tidal incursions coincide)—Separation in time between lines is approximately 21 min. (29° = 1 hr.)

············ Corange lines (lines along which tidal amplitudes are equal)

←—— Direction of tide propogation

There is a marked diurnal inequality for tides on the North Coast. In general, mean tidal ranges increase from south to north, with averages of 2 m at Victoria, 3.4 m at Bella Bella, 4.9 m at Prince Rupert and 5.0 m at Queen Charlotte City. A notable exception is Masset, with a range of only 2.7 m, probably because it is open to the movements of the Pacific Ocean. Tidal ranges along the outer coast average about 3 m.

Tidal currents in the open ocean are usually very difficult to distinguish. Runoff, local winds, and offshore meteorological conditions generally dominate surface movements.

### 2.2.4 TEMPERATURE AND SALINITY

High salinity and cold water temperatures tend to retard the degradation of spilled oil. It is doubtful that the relatively low salinities of nearshore and estuarine areas would significantly increase degradation and thereby reduce onshore impacts, since this effect would likely be offset by nearshore water temperatures, which tend to be colder than offshore temperatures (see below).

The northeastern Pacific waters away from coastal influences are characterized by 3 distinct layers:

1. A surface layer about 100 m thick showing seasonal variation in temperature but little change in salinity
2. A stable transitional (halocline) layer about 100 m thick where temperature changes little, but salinity increases rapidly with depth
3. A lower zone where temperature decreases and salinity increases slowly with depth

Near the coastal areas, however, there are local variations due to coastal warming and freshwater runoff.

In spring, there is very little variation in surface salinity for the

Plate 6: Estuaries and mudflats are low wave-energy environments with very fine grain sediments, making them particularly susceptible to chronic oil spill contamination.

*(Photo by Jim Slater)*

North Coast. The lowest salinities (<31 $^{0}/oo$) are found along the eastern mainland shores, and the highest (about 32 $^{0}/oo$ are at the western approaches to Queen Charlotte Sound and Dixon Entrance (Dodimead, 1980).

In summer, much lower salinities are evident, and marked salinity gradients are found in northeast Hecate Strait and north Dixon Entrance. These gradients are attributed to the northern outflow of the Nass and Skeena Rivers. Runoff from these rivers into Chatham Sound reaches its peak in June. Most of this brackish water escapes seaward along the north side of Dixon Entrance or through Clarence Strait. A tongue of cold, less saline water in southern Hecate Strait is more pronounced in summer due to increased flushing. A cooler band of water results from upwelling along the eastern side of Hecate Strait. In winter, the halocline sinks due to increased wind mixing, and the thermocline decays. Dixon Entrance and Hecate Strait are nearly isothermic to the bottom, and remain so through to early spring.

Surface salinity usually increases seaward to a high of 33 $^{o}$/oo. Close to the outer coasts of the Queen Charlottes and Vancouver Island surface salinities range from 31-32 $^{o}$/oo. Inner Hecate Strait usually exhibits much lower salinities due to freshwater runoff, especially during freshet in late spring to early summer. There are two known features of advection which can alter the temperature and salinity of the North Coast:

1. The northward surface flow through Hecate Strait in winter introduces relatively warm, saline water into the Chatham Sound area, northern Hecate Strait, and eastern Dixon Entrance.
2. The flushing of fresh water seaward from Dixon Entrance in summer results in a deep intrusion of cool, saline water from the Pacific Ocean.

Surface temperatures decrease from offshore areas seaward in all seasons. Annual ranges are from 6°C to 14°C, although temperatures can exceed 20°C in coastal waters. Warmest temperatures usually occur in central Queen Charlotte Sound; coolest temperatures are in Dixon Entrance.

Relatively cold, saline water off the west coast of Vancouver Island in summer is most evident under the influence of northwest winds. This is attributed to the upwelling of deep water, perhaps from 200-300 m. Generally speaking, water temperatures are cooler along exposed nearshore regions than they are further out to sea (Figure 2.8). This results from upwelling.

### 2.2.5 DISSOLVED OXYGEN

Dissolved oxygen is a critical component in the biodegradation of oil. Recent publications suggest that oil has no significant direct effect on oxygen levels in the open ocean where surface oxygen levels are near saturation year round. Most vulnerable are the mouths of enclosed estuaries or embayments. Considerable oxygen variations are evident where effluents with high biochemical oxygen demand (BOD) are discharged. Between the months of August and October in Chatham Sound, significant variations are found where upwelling reduces dissolved oxygen levels. In the Hecate Strait region, dissolved oxygen levels decrease gradually with depth due to reduced mixing.

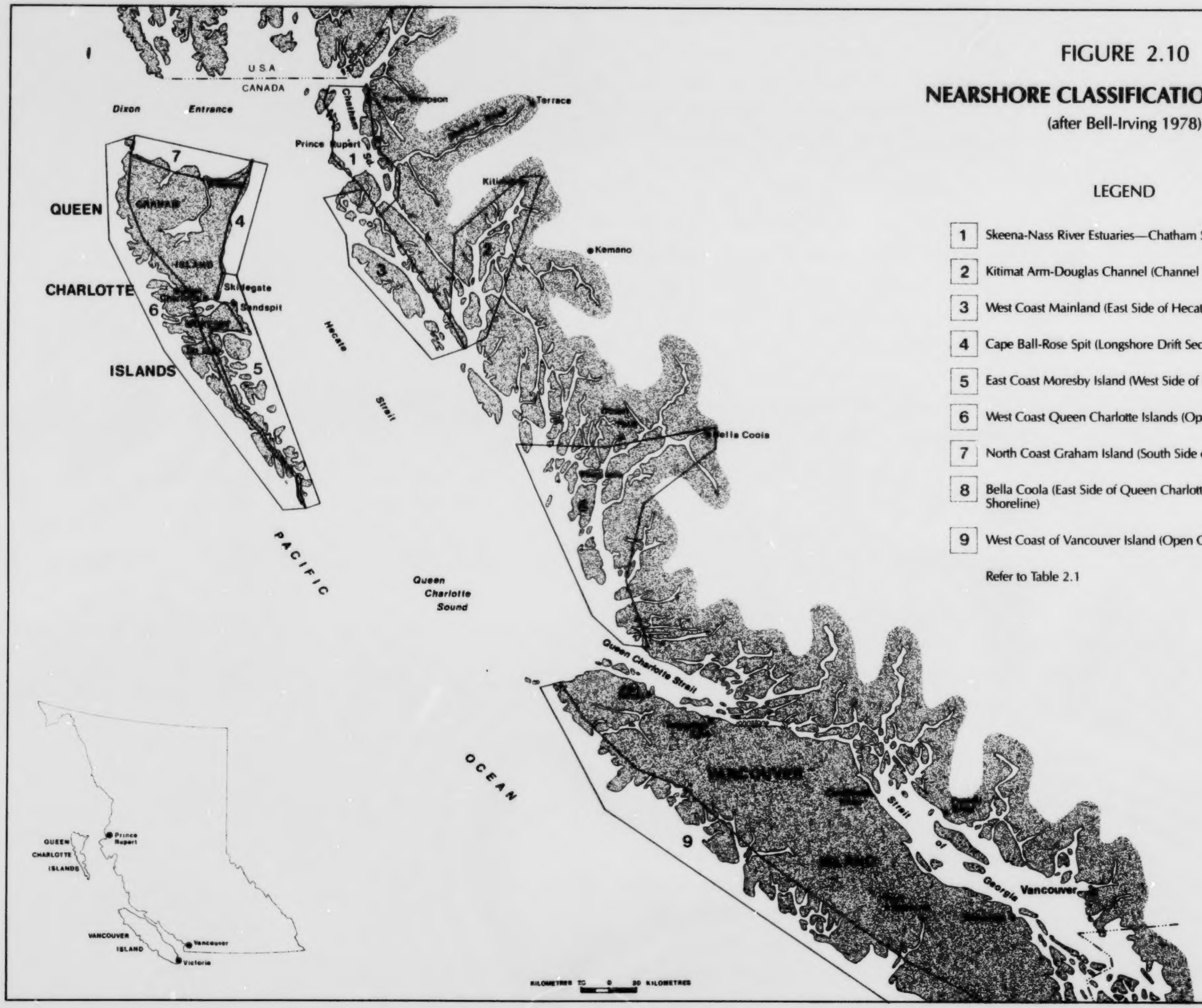
The high BOD of industrial effluents discharged into some North Coast estuaries and inlets has periodically caused significant reductions in natural levels of dissolved oxygen. In 1961, the pulp mill at Port Edward near Prince Rupert had so heavily polluted the waters of Wainwright Basin and Porpoise Harbour that there were concentrations of zero dissolved oxygen at various depths. Between 1976-80, however, measurements of dissolved oxygen had returned to within 80% of their natural levels (Ho, 1978). In areas other than embayments or inlets subject to high BOD from industrial discharges (such as pulp mills and sewage outfalls), dissolved oxygen concentrations are usually at or near saturation levels.

### 2.2.6 SHORE TYPES

Table 2.1 illustrates the nearshore characteristics of the study area. It should be noted, before examining Tables 2.1 and 2.2, that they are indices of physical shoreline sensitivity to spilled oil for a given coastal regime, and as such do not necessarily indicate a particular area's biological sensitivity.

#### 2.2.6.1 Oil Retention Potential

Oil retention potential (ORP) is an index of shoreline susceptibility and sensitivity to oil spills based on the geological character (substrate) of the coastline and the energy environment of the shore. For example, vertical cliffs have high removing factors and no retaining factors and therefore have the lowest oil retention index, whereas marshes have high retaining factors and low removing factors and therefore have the highest oil retention potential.


U.S.A.
CANADA
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Prince Rupert
Terrace
Kitimat
Kemano
QUEEN CHARLOTTE ISLANDS
Skidegate
Sandspit
Hecate Strait
Bella Coola
PACIFIC OCEAN
Queen Charlotte Sound
Queen Charlotte Strait
VANCOUVER
Strait of Georgia
Vancouver
1
2
3
4
5
6
7
8
9
QUEEN CHARLOTTE ISLANDS
Prince Rupert
VANCOUVER ISLAND
Vancouver
Victoria
KILOMETRES 20 0 20 KILOMETRES

FIGURE 2.10

**NEARSHORE CLASSIFICATION REGIONS**

(after Bell-Irving 1978)

LEGEND

| | |
|---|---|
| 1 | Skeena-Nass River Estuaries—Chatham Sound (Estuarine) |
| 2 | Kitimat Arm-Douglas Channel (Channel Shoreline) |
| 3 | West Coast Mainland (East Side of Hecate Strait) |
| 4 | Cape Ball-Rose Spit (Longshore Drift Sector) |
| 5 | East Coast Moresby Island (West Side of Hecate Strait) |
| 6 | West Coast Queen Charlotte Islands (Open Coast) |
| 7 | North Coast Graham Island (South Side of Dixon Entrance) |
| 8 | Bella Coola (East Side of Queen Charlotte Sound-Channel Shoreline) |
| 9 | West Coast of Vancouver Island (Open Coast) |

Refer to Table 2.1

## TABLE 2.1

## SHORELINE SENSITIVITY INDEX BASED ON NEARSHORE CLASSIFICATIONS —PER CENT OCCURRENCES FOR THE QUEEN CHARLOTTES—PRINCE RUPERT—KITIMAT—BELLA COOLA—WEST COAST VANCOUVER ISLAND

See Fig. 2.10

| Area | Substrate | | | Exposure | | | Slope | | | Estuarine Zones† |
|---|---|---|---|---|---|---|---|---|---|---|
| | Bedrock | Coarse Grain | Fine Grain | Open Coast | Partially Protected | Protected | Low | Medium | High | A comparison of the relative occurrence, on a percent scale, of estuarine zones for each area |
| 1 | 83 | 7 | 10 | 19 | 61 | 20 | 20 | 58 | 22 | 10.4% |
| 2 | 88 | 4 | 8 | 0 | 9 | 91 | 6 | 17 | 77 | 9.6% |
| 3 | 84 | 9 | 7 | 14 | 31 | 55 | 14 | 47 | 39 | 3.8% |
| 4 | 14 | 3 | 83 | 89 | 11 | 0 | 51 | 29 | 20 | 24.7% |
| 5 | 87 | 8 | 5 | 54 | 29 | 17 | 6 | 50 | 44 | 5.6% |
| 6 | 85 | 4 | 11 | 50 | 29 | 21 | 14 | 31 | 55 | 12.5% |
| *7 | 56 | 3 | 41 | 40 | 50 | 10 | 49 | 37 | 14 | 12.0% |
| 8 | 84 | 8 | 8 | 2 | 17 | 81 | 5 | 34 | 61 | 6.2% |
| 9 | 66 | 11 | 22 | 35 | 43 | 22 | 21 | 49 | 30 | 15.2% |
| | | | | | | | | | | 100.0% |

Area (see Fig. 2.10)

| | |
|---|---|
| 1 | Skeena - Nass River Estuaries - Chatham Sound (Estuarine) |
| 2 | Kitimat Arm - Douglas Channel (Channel Shoreline) |
| 3 | West Coast Mainland (East Side of Hecate Strait) |
| 4 | Cape Ball - Rose Spit (Longshore Drift Sector) |
| 5 | East Coast Moresby Island (West Side of Hecate Strait) |
| 6 | West Coast Queen Charlotte Islands (Open Coast) |
| *7 | North Coast Graham Island (South Side of Dixon Entrance) |
| 8 | Bella Coola (East Side of Queen Charlotte Sound - Channel Shoreline) |
| 9 | West Coast Vancouver Island (Open Coast) |

† Estuarine Zones are defined as "areas at the mouths of rivers, visible as gravel bars and mud flats" (Fisheries and Environment Canada, 1978).

* Does not include Naden Harbour, Masset Sound or Masset Inlet.

(After Fisheries and Environment Canada, 1978)

Oil Retention Potential depends on three factors: substrate, slope and exposure. Broadly speaking, ORP increases with decreasing substrate size, slope, and exposure. Table 2.2 outlines ORP's for various types of intertidal habitats.

TABLE 2.2

OIL RETENTION POTENTIALS FOR INTERTIDAL HABITATS

| | | SLOPE | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Low | Medium | High | Low | Medium | High | Low | Medium | High | Low | Medium | High | Low | Medium | High | Low | Medium | High |
| EXPOSURE | Exposed | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | N | 3 | 3 | N | 1 | 1 | 1 |
| | Partially Exposed | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 3 | 3 | N | 3 | 3 | N | 1 | 1 | 1 |
| | Partially Sheltered | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | N | 3 | 3 | N | 2 | 2 | N |
| | Sheltered | 2 | 2 | 2 | 2 | 2 | 2 | N | N | N | 3 | 3 | N | 3 | 3 | N | 2 | 2 | N |
| | | Bedrock | | | Boulder | | | Gravel-Cobble | | | Sand | | | Mud | | | Man-Made | | |
| | | SUBSTRATE | | | | | | | | | | | | | | | | | |

Oil Retention Potential

1 - Low

2 - Moderate

3 - High

N - No Available Data

(after Trans Mountain Pipe Line Co. Ltd. 1980)

In reviewing the tables, it should be borne in mind that an area indicating a very low oil retention potential may include a number of scarce biological resources that would be severely impacted by an oil spill. Moreover, section 5.8.3 lists 14 variables which would influence the onshore effects of spilled oil, of which "shore type" (physiography of spill area) is one. These tables are therefore most applicable to the logistics likely to be involved in onshore oil spill cleanup operations for a given area.

For a more complete inventory of oil retention potentials and wave energy environments, refer to Map C-1, Map Folio Vol. XVII, Trans Mountain Pipe Line (1980), or Table 5.4 of this document.

**Plate 7:** Areas with low oil retention potentials may harbour scarce biological resources with high sensitivities to hydrocarbon contamination (Strandflats on Campania Island).

*(Photo by Jim Slater)*

## 2.2.7 SEISMICITY

Adequate knowledge of seismicity and bathymetry (seafloor shifting, slope, submarine slides, slumping, substrate type and stability, tsunamis) is necessary for the safe operation of offshore drilling at any stage of development. This includes the construction and operation of nearshore facilities, particularly if they are located at the heads of inlets or at ports with large tidal volumes.

Seismicity is considered to be the most significant risk to the offshore hydrocarbon industry for the North Coast region (Ellers, 1982 and Yorath, pers. comm., 1982).

However, it is important to take into account the following points when considering seismic risks:

a. The probability that seismic activity will occur during drilling is remote, owing to the short duration of drilling activity relative to the historical frequency of earthquake activity on the North Coast;
b. Industry experience indicates that only active faults pose a serious problem, and then only if the rig is drilling through a fracture zone during a seismic event. Again, industry experience in the seismically active San Andreas region indicates that such an event would cause the hole to seal itself, thereby circumventing a blowout;
c. The risks from seismicity are attenuated by the assumption that there would be considerable mitigation by engineering design, standard drilling procedures, and compliance with stringent government regulations.

The offshore region of the British Columbia North Coast is the most seismically active area in Canada (Alley and Thompson, 1978). The most active earthquake zones for the study area correspond to the boundaries between the major lithospheric plates (see Figure 2.11), which are:

1. The Queen Charlotte - Fairweather fault system (Pacific - American plates)
2. The Offshore ridge - fracture zone system (Pacific - Juan de Fuca plates)

The greatest amount of seismic energy is released along the Queen Charlotte - Fairweather fault system, and at present a significant accumulation of strain may be available for release in the form of earthquakes in the Vancouver Island -Puget Sound area (Figure 2.12). Most earthquakes on the West Coast, however, occur beneath the ocean or near the continental margin. South of the Queen Charlotte Islands the zone of seismicity is located in a large area of ocean floor west of Vancouver Island. It is an area of intense seismicity: during the 76-year period from 1899 to 1974 inclusive, 1,268 earthquakes were recorded for Graham Island. Shaking produced by 41 of these quakes was sufficient to have been felt by human inhabitants. Of these 41, one is regarded as a great earthquake (magnitude $\geq 8$ on the Richter scale), six as major (magnitude between 7 and 8), and thirty-one as economically important (magnitude 5 to 7). The remaining three were less than magnitude 4. The great earthquake occurred on August 22, 1949 (53°37'N Lat., 133°16'W Long.) off the west coast of Graham Island. With a magnitude of 8.1 Richter, it was one of the strongest earthquakes felt in Canada (Alley and Thompson, 1978). See Table 2.3 for details.

#### 2.2.7.1 Liquefaction of Sediments

A number of factors, including seismic stress (earthquakes, tremors, volcanic eruptions) can cause bottom sediments to lose their cohesion and liquefy to a depth of 10 m below the sea floor (U.S. Dept. of Interior, 1981). This could be hazardous to bottom-mounted facilities such as gravity platforms, offshore terminals and, especially, pipelines.

### 2.2.8 THERMOGENIC GAS CHARGING

Thermogenic gas pockets are formed when a gas, such as $CO_2$ derived from hydrocarbon sources, migrates toward the surface of the sea bed along

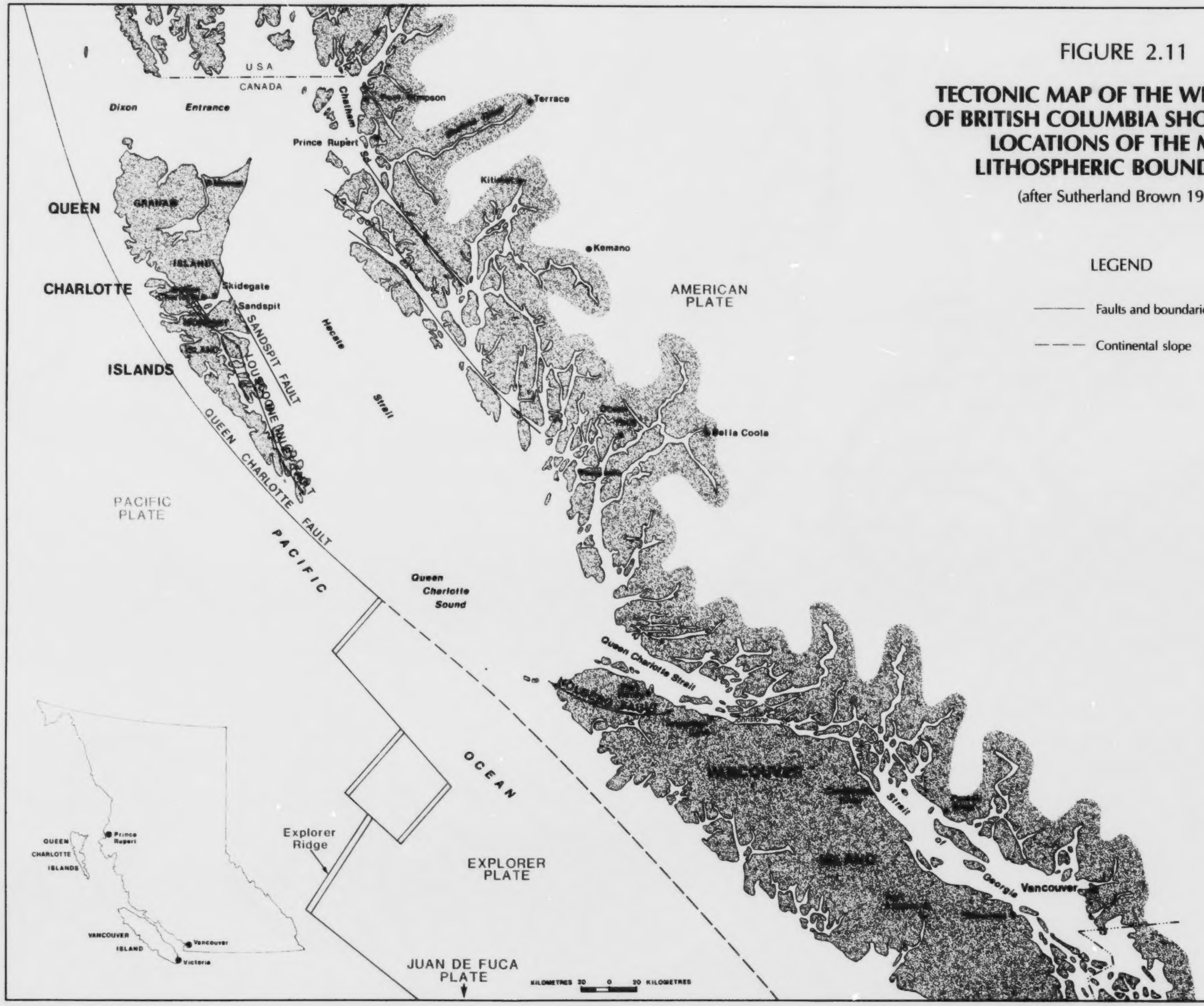
USA
CANADA
Dixon
Entrance
Chatham
Port Simpson
Terrace
Prince Rupert
Kitimat
Kemano
QUEEN
CHARLOTTE
ISLANDS
GRAHAM
ISLAND
Skidegate
Sandspit
SANDSPIT FAULT
LOUSCOONE INLET FAULT
Hecate
Strait
AMERICAN
PLATE
Bella Coola
QUEEN CHARLOTTE FAULT
PACIFIC
PLATE
PACIFIC
OCEAN
Queen
Charlotte
Sound
Queen Charlotte Strait
VANCOUVER
ISLAND
Strait
of
Georgia
Vancouver
Explorer
Ridge
EXPLORER
PLATE
JUAN DE FUCA
PLATE
KILOMETRES 20 0 20 KILOMETRES
QUEEN
CHARLOTTE
ISLANDS
Prince
Rupert
VANCOUVER
ISLAND
Vancouver
Victoria

FIGURE 2.11

TECTONIC MAP OF THE WEST COAST OF BRITISH COLUMBIA SHOWING THE LOCATIONS OF THE MAIN LITHOSPHERIC BOUNDARIES

(after Sutherland Brown 1968)

LEGEND

——— Faults and boundaries

– – – Continental slope

shallow surface faults and either escapes from the sea bed or accumulates in near-surface sediments (U.S. Dept. of Interior, 1981). This may become a zone of highly charged gas sediments under great pressure and may cover an area several kilometers in diameter. Thermogenic gas charging is considered a very high hazard to any drilling program, since penetration into such a zone of high pressure could result in a blowout and subsequent explosion. Adequate geologic testing is necessary for identification of such areas.

### 2.2.9 BIOGENIC GAS CRATERING

Peats and organic-rich sediments may become covered by relatively thin layers of recently formed sediments. The decomposition of this organic material can then result in high concentrations of methane gas at relatively shallow depths and low pressures below the sea floor. These gas-charged sediments exhibit a lower shear strength than deposits without gas. Therefore they present potential foundation problems for many offshore facilities, such as gravity platforms, sea terminals, jack-up rigs, and pipelines. Since blowouts of gas from shallow depths have been documented, drilling programs must take this potential hazard into consideration.

## 2.3 DATA GAPS FOR PHYSICAL AND CHEMICAL PARAMETERS

The following is an assessment of the adequacy of physical and chemical data.

### 2.3.1 PHYSICAL OCEANOGRAPHY

#### 2.3.1.1 Bathymetry

The largest scale for a bathymetric chart covering the entire British Columbia coast is 1:1,000,000 (See Figure 2.2). A larger scale series (1:250,000) is being prepared by the Hydrographic Service of the Department of Fisheries and Oceans. To date, the series is incomplete for almost the entire area covered in this report, with the exception of a portion of Queen Charlotte Sound and most of Vancouver Island. Detailed bathymetric charts are not available for Dixon Entrance, Chatham Sound, the west coast of the Queen Charlotte Islands, Hecate Strait, and southern Queen Charlotte Sound.

## TABLE 2.3

## EARTHQUAKES BETWEEN 1912 AND 1974 IN THE QUEEN CHARLOTTE ISLANDS REGION (50°N–57°N)

(Source: Rogers 1982.)
See also Fig. 2.12

| Map Reference Number | Year | Latitude | Longitude | Magnitude (Richter) |
|---|---|---|---|---|
| 1 | 1912 | 51°00' | 131°00' | 6.5 |
| 2 | 1918 | 50°15' | 126°50' | 7.0 |
| 3 | 1920 | 50°36' | 129°52' | 6.4 |
| 4 | 1921 | 54°00' | 134°00' | 6.5 |
| 5 | 1921 | 53°20' | 134°10' | 5.0 |
| 6 | 1923 | 53°30' | 133°00' | 5.0 |
| 7 | 1924 | 50°00' | 130°14' | 6.0 |
| 8* | 1927 | 57°40' | 136°04' | 5.0 |
| 9* | 1927 | 57°40' | 136°04' | 5.0 |
| 10* | 1927 | 57°41' | 136°04' | 5.0 |
| 11* | 1927 | 59°19' | 136°13' | 5.0 |
| 12 | 1929 | 50°30' | 130°45' | 6.1 |
| 13 | 1929 | 51°30' | 130°44' | 7.0 |
| 14 | 1930 | 52°29' | 132°02' | 5.7 |
| 15 | 1936 | 52°55' | 131°45' | 6.0 |
| 16 | 1936 | 52°30' | 132°03' | 5.0 |
| 17 | 1938 | 53°00' | 132°10' | 6.3 |
| 18 | 1938 | 53°00' | 132°10' | 5.2 |
| 19 | 1940 | 54°00' | 134°00' | 5.5 |
| 20 | 1944 | 51°30' | 131°10' | 6.2 |
| 21 | 1945 | 53°52' | 133°21' | 6.3 |
| 22 | 1946 | 50°30' | 125°30' | 7.3 |
| 23* | 1948 | 53°22' | 132°43' | 6.5 |
| 24 | 1949 | 53°37' | 133°16' | 8.1 |
| 25 | 1949 | 54°57' | 133°25' | 4.5 |
| 26 | 1949 | 54°13' | 133°36' | 4.6 |
| 27* | 1949 | 54°52' | 134°19' | 4.9 |
| 28 | 1949 | 52°52' | 131°19' | 5.1 |
| 29 | 1949 | 55°04' | 134°00' | 5.0 |
| 30 | 1949 | 52°25' | 131°52' | 5.0 |
| 31 | 1949 | 52°38' | 132°06' | 5.0 |
| 32 | 1949 | 52°46' | 132°06' | 4.9 |
| 33* | 1949 | 56°04' | 135°16' | 4.9 |
| 34 | 1949 | 54°40' | 133°52' | 5.0 |
| 35 | 1949 | 53°03' | 132°44' | 5.3 |
| 36 | 1949 | 53°37' | 132°58' | 4.9 |
| 37* | 1949 | 55°09' | 132°34' | 5.0 |
| 38* | 1949 | 56°03' | 135°41' | 6.2 |
| 39* | 1949 | 56°01' | 135°54' | 5.1 |
| 40* | 1950 | 54°30' | 136°00' | 4.5 |
| 41* | 1950 | 54°19' | 134°37' | 5.5 |
| 42 | 1954 | 54°10' | 133°37' | 4.5 |
| 43 | 1954 | 53°34' | 133°27' | 4.5 |
| 44 | 1956 | 51°36' | 131°22' | 6.5 |
| 45 | 1956 | 54°33' | 131°40' | 6.4 |
| 46 | 1957 | 50°51' | 130°21' | 6.2 |
| 47* | 1958 | 56°08' | 139°13' | 5.3 |
| 48* | 1958 | 59°00' | 137°10' | 7.9 |
| 49 | 1960 | 50°52' | 130°05' | 4.6 |
| 50 | 1963 | 50°52' | 129°39' | 4.1 |
| 51 | 1963 | 50°18' | 127°44' | 4.5 |
| 52 | 1963 | 52°05' | 131°29' | 4.2 |
| 53 | 1963 | 52°10' | 130°58' | 4.0 |
| 54 | 1964 | 51°03' | 129°28' | 4.1 |
| 55 | 1966 | 54°10' | 134°10' | 5.0 |
| 56 | 1968 | 50°43' | 130°15' | 4.1 |
| 57 | 1970 | 52°50' | 132°29' | 4.0 |
| 58 | 1970 | 51°46' | 130°45' | 7.0 |
| 59 | 1971 | 51°01' | 129°40' | 4.2 |
| 60 | 1971 | 50°56' | 130°30' | 6.4 |
| 61* | 1971 | 55°20' | 134°00' | 5.3 |
| 62 | 1973 | 54°27' | 133°07' | 4.0 |

* Not shown on Figure 2.12.

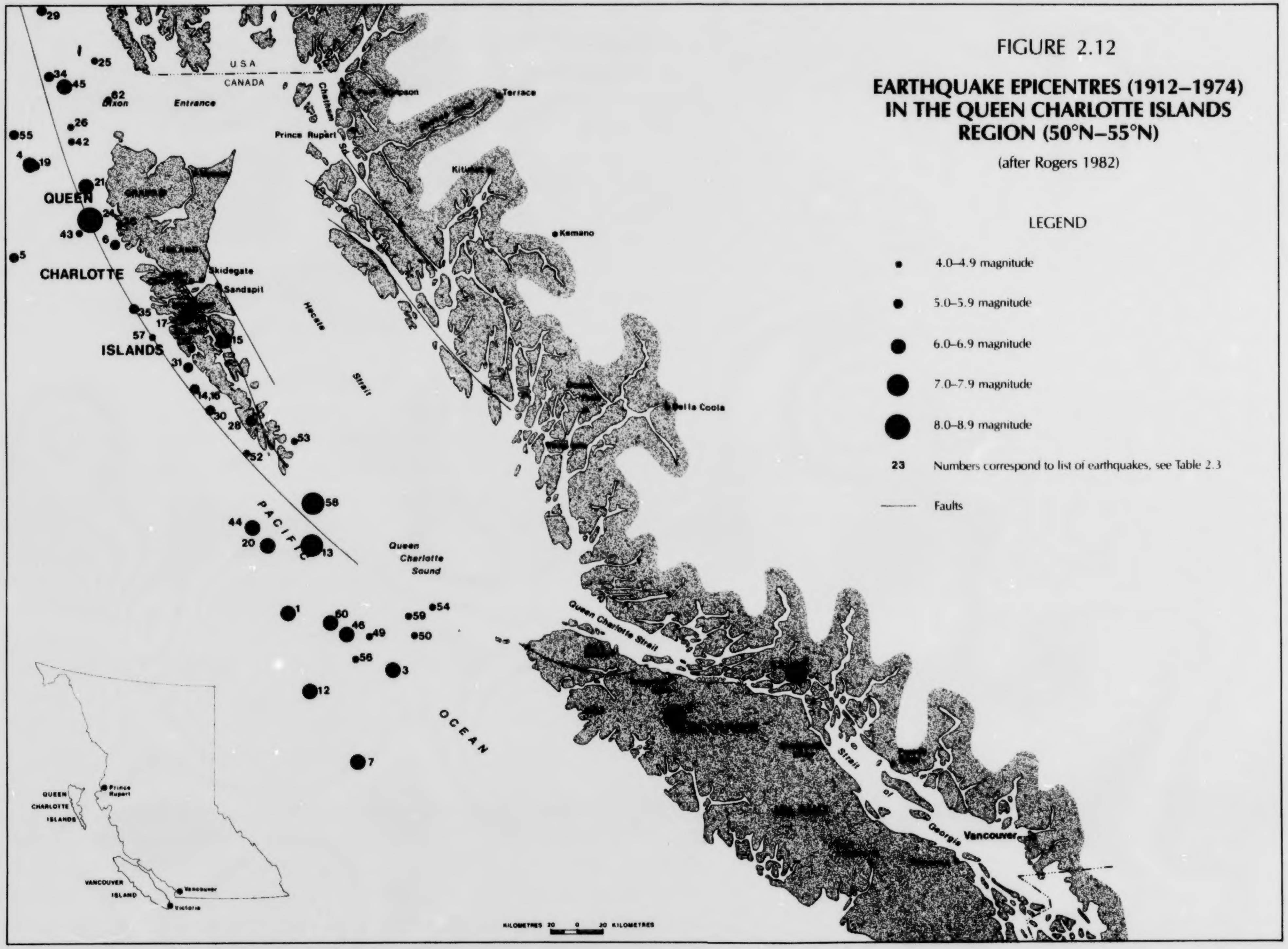

FIGURE 2.12

EARTHQUAKE EPICENTRES (1912–1974) IN THE QUEEN CHARLOTTE ISLANDS REGION (50°N–55°N)

(after Rogers 1982)

LEGEND
● 4.0–4.9 magnitude
● 5.0–5.9 magnitude
● 6.0–6.9 magnitude
● 7.0–7.9 magnitude
● 8.0–8.9 magnitude
23 Numbers correspond to list of earthquakes, see Table 2.3
—— Faults
U.S.A.
CANADA
Dixon
Entrance
Prince Rupert
Port Simpson
Terrace
Kitimat
Kemano
Chatham Sd.
QUEEN
CHARLOTTE
ISLANDS
Skidegate
Sandspit
Hecate
Strait
Bella Coola
PACIFIC
OCEAN
Queen
Charlotte
Sound
Queen Charlotte Strait
Strait of Georgia
Vancouver
29
25
34
45
62
26
42
55
4
19
21
24
43
6
5
35
17
57
15
31
14,16
30
28
53
52
58
44
20
13
1
60
46
49
59
54
50
56
3
12
7
QUEEN
CHARLOTTE
ISLANDS
Prince Rupert
VANCOUVER
ISLAND
Vancouver
Victoria
KILOMETRES 20 0 20 KILOMETRES

In general, knowledge of the bathymetry of the study area is either sketchy or not up to date, especially for the west coast of the Queen Charlottes. Only antiquated data is available for some areas. For example, the only available navigational chart for the west coast of the Queen Charlottes from Tasu Sound to Port Louis is based on a survey conducted in 1935-36.

#### 2.3.1.2 Weather Forecasting

The most important information applicable to the prediction of oil spill movements and safe operating procedures is "real time" accurate weather forecasting. This involves being able to gather reliable and comprehensive meteorological data in the spill area at the time of the spill. To date no such facilities exist in the study area.

Very limited weather data is available for the west coast of the Queen Charlottes. This has resulted in an inadequate knowledge of local wind variations and extremes for the entire outer coast of the Queen Charlottes. The only direct weather measurements taken off the B.C. coast are from passing ships. British Columbia Hydro is planning to install wind speed recording instruments at Masset, Sandspit and Tlell (Queen Charlotte Observer, 24/09/81). In addition, Seakem Oceanography Ltd. plans to install six wave buoys in September of 1982: two near Learmonth Bank in Dixon Entrance, one off Bonilla Island, one off McInnes Island, one in Hecate Strait, and one in Queen Charlotte Sound. Despite these recent efforts, facilities for gathering direct or on-site weather information remain inadequate for predicting slick movements, rates of weathering, and the behaviour of oil in the water column. This subject is discussed further in Section 6.2.

#### 2.3.1.3 Water Temperature and Salinity

There are no published summaries or interpretations of water temperature and salinity data for the west coast of the Queen Charlotte Islands. With the exception of major inlets with large industrial developments or salmon-bearing rivers, most inlets along the west coast of Vancouver Island and the northern mainland have little or no data available for defining winter temperature and salinity structures.

### 2.3.1.4 Seismicity

Knowledge is generally poor for the locations of earthquakes prior to the mid 1960's due to a lack or absence of equipment and stations. A serious regional bias exists for recording earthquakes less than magnitude 4.0 due to the relative preponderance of seismographic stations in the Lower Mainland and southern Vancouver Island. The Geological Survey of Canada is, however, planning to install three new seismic stations on the North Coast during the summer of 1982, one each at Bella Bella, Ocean Falls, and Cape St. James. Further shelf faulting and sedimentation studies would provide basic information on geologic hazards in the study area, including locations of probable active faults, potentially unstable sediments, and erosional and depositional areas on the continental shelf.

### 2.3.1.5 Circulation

There are virtually no direct, long-term current measurements available for nearshore waters off the west coast of the Queen Charlottes. Direct current measurements for the west coast of Vancouver Island have only recently been taken; most are still being analyzed. Circulation patterns can only be inferred from general oceanic currents observed in the northeast Pacific.

## 2.3.2 CHEMICAL OCEANOGRAPHY

Basic data on the background concentrations of hydrocarbons in seawater, marine organisms, and sediments are necessary to assess the possible effects of drilling and production, or the effects of a major spill or blowout.

### 2.3.2.1 Hydrocarbons

To date, very little is known about background hydrocarbon levels for the North Coast, with the exception of the Douglas Channel region. Data on hydrocarbon levels would serve as an indicator of levels of petroleum input. Studies based on this information could provide predictive data for hydrocarbon degradation rates. A natural oil seep such as the one reportedly in the Tar Islets area off southeast Moresby Island might be an appropriate site to investigate hydrocarbon levels and the adaptation of local biota to their presence (Beech, pers. comm., 1982).

### 2.3.2.2 Trace Metals

The most significant impact of crude oil on trace metals in the marine environment is likely to be its adverse effect on their bioavailability and remobilization from sediments. Trace metals are less sensitive indicators of petroleum input than are hydrocarbons and nutrients. Consequently, the effects of petroleum on trace metal distributions in marine systems are probably very small. However, because trace metal contamination is often associated with drilling operations, near-field baseline data are needed to evaluate the potential effects of offshore productions on levels of these materials (MacKnight et al., 1981). Studies are also necessary to determine whether certain trace metals may be sensitive to spilled oil, and whether some of these may be limiting factors in the metabolic cycles of certain plankton. At present there is no standard method for measuring the bioavailability of trace metals, nor are there any available measurements of short- or long-term temporal variability for any trace metals (e.g., Cu, Cd, Pb, Hg, Zn).

### 2.3.2.3 Productive Areas

Baseline data, such as temperature, salinity, nutrients, and dissolved oxygen for surface waters of highly productive areas, where the greatest biological impacts are likely to occur, are clearly lacking. Of particular importance are estuaries, other low-energy environments, and regions of upwelling and convergence. These data are required to determine the factors that characterize productive areas and to monitor changes that would occur in the event of an actual spill, including recovery rates and long-term effects.

### 2.3.2.4 Tarballs

Tarballs serve as useful qualitative indicators for petroleum contamination (e.g., for determination of oil type or degree of weathering). The only attempts to collect tarballs in the North Coast region of British Columbia have been in the vicinity of Douglas Channel. Tarballs have also been sighted on the east coast of the Queen Charlotte Islands (K. Moore, pers. comm., 1982).

### 2.3.2.5 Nutrients

Crude oils have no known direct effects on nutrient levels (Trans Mountain, 1980a). If this is true, they would not be of major importance in determining the distribution or fate of spilled crude oils and their degradation products. Bacteria involved in the biodegradation of oil may competitively utilize nutrients and thus indirectly limit phytoplankton growth. Large knowledge gaps remain for nutrient distributions in the study area, and the sensitivity of nutrients to spilled oil remains poorly understood.

## 2.4 SUMMARY

It is evident from a review of this chapter that much of the information for the area of reference has not yet been organized into an accessible or usable form that would allow for the comprehensive environmental assessment, planning and management of the offshore oil and gas industry.

The North Coast region of British Columbia, particularly the west coast of the Queen Charlotte Islands, remains poorly understood in terms of its meteorological, geophysical and oceanographic characteristics. Exceptions are major inlets with large, industrial developments and/or salmon-bearing rivers, such as parts of Chatham Sound and Douglas Channel.

Since it is expected that offshore activities will be concentrated in Hecate Strait, Queen Charlotte Sound, and Dixon Entrance, it will likely be these areas that will be the focus of extensive and rigorous data gathering for priority concerns (i.e., meteorological, geophysical and oceanographic parameters expected to be of particular significance to offshore industry in terms of operating safety and environmental impacts). This, however, does not preclude the necessity of establishing an adequate data base for non-target areas such as Chatham Sound, Queen Charlotte Strait, and the west coasts of the Queen Charlotte and Vancouver Islands, since they too may be directly or indirectly affected by offshore industry. These concerns are identified and discussed in greater detail in section 6.2.

# CHAPTER 3

# OFFSHORE BIOLOGICAL ENVIRONMENT

Don Tillapaugh
Ken Turner

# CHAPTER 3—OFFSHORE BIOLOGICAL ENVIRONMENT

## 3.1 INTRODUCTION

The purpose of this chapter is to familiarize the reader with the biological resources of the north British Columbia coast and to discuss potential environmental impacts which require management. Inventory information presented is the most current available. It has been updated by personal interviews and correspondence with experts in the field. Information on potential environmental impacts is drawn from the world literature. Discussion of impacts centers on two themes: 1) those attributable to the routine activities of offshore exploration and production, and 2) those attributable to blowouts and major spills, (i.e., non-routine events).

This preliminary report does not include an exhaustive listing of studies conducted on the impacts of oil on the marine environment. Instead it attempts to integrate and synthesize those studies considered to be of particular relevance to the British Columbia situation. Inconsistencies, controversies, and data gaps are identified. The summary overview of potential environmental impacts provided at the end of this chapter gives the reader a clear understanding of the environmental risks involved in the development of offshore petroleum resources. Reference documents cited in the text can be used to investigate the broad range of environmental concerns discussed.

## 3.2 INVENTORY OF MARINE BIOLOGICAL RESOURCES–INTRODUCTION

This section briefly outlines current knowledge regarding the abundance and location of marine biological resources of the British Columbia coastline and coastal waters. Every effort was made to update existing inventory information through correspondence and personal interviews with recognized experts in the field. This information is provided in summary form and mapped where possible. References are provided for those who wish to obtain more detailed information.

### 3.2.1 BACTERIA

Research on marine bacteria at the mouth of the Fraser River indicates that primary production by these organisms in turbid river plumes can exceed that of marine phytoplankton in open ocean waters. Most of these bacteria are attached to detritus and suspended silt (Albright, advance copy). Further bacteriological work in the Skeena River estuary is planned for the near future. Westlake and Cook (1980) in the United States have investigated the occurrence and activity of oil-degrading bacteria, yeasts, and fungi in Puget Sound and the Strait of Juan de Fuca. They concluded that these types of microbes were ubiquitous in the waters, beaches, inter-tidal and subtidal sediments of their study area. As yet, no investigations into oil degradation by marine bacteria or other oceanic microorganisms have been conducted in British Columbia. The need for this type of research should be assessed and appropriate investigations carried out.

### 3.2.2 PLANKTON INVENTORY

Ecological Role of Phytoplankton:

Phytoplankton are unicellular, free-floating plants that convert inorganic carbon (e.g., $CO_2$) to high energy organic carbon molecules by photosynthesis. Because this conversion process directly utilizes sunlight, it is termed primary productivity. Primary production supplies almost all the energy required for the higher trophic levels in pelagic (open ocean) systems. It is sustained by nutrients, sunlight, and water column stratification. Perpetual nutrient enrichment allows certain areas within the ocean to constantly sustain a high level of primary productivity and thus become extremely productive biologically. Upwelling, tidal convergence, and oceanfloor scouring are examples of physical phenomena that help keep the nutrient levels in these areas constantly elevated. One such enriched area is found off the mouth of the Strait of Juan de Fuca (Denman, 1980), with the Fitz Hugh Sound area tentatively identified as another (Ian Perry, pers. comm., 1982). Additional zones may be located in future. Phytoplankton can undergo radical fluctuations in abundance as conditions for their growth vary. When a tremendous increase in their population occurs, a "bloom" condition is said to exist. "Red Tide" is a typical example of this occurrence.

Ecological Role of Zooplankton:

Zooplankton are animals found passively floating or weakly swimming in the water column. Some of these animals are planktonic for their entire life history while others are planktonic only during certain life stages (larval stages for instance). There are both herbivorous (those that consume phytoplankton) and carnivorous zooplankton (those that consume other zooplankton species). Zooplankton are important secondary producers and serve as a critical food source for higher trophic levels, including commercial fish species. Large populations of zooplankton as well as animals from higher trophic levels, such as fish, marine birds, and marine mammals, are supported in areas of high primary productivity. Some of the major research papers concerned with marine productivity in this area are listed in Table 3.1.

These biologically productive areas are especially vulnerable to routine activities associated with offshore oil production and to environmental catastrophies such as oil spills.

### 3.2.3 MARINE PLANTS

#### Benthic Algae

Benthic algae are those marine plants growing directly on (or attached to) the ocean floor. The most commonly recognized species of this group are the large brown kelps [Nereocystis (bull kelp) and Macrocystis] which form extensive "beds" in some areas. These "beds" are ecologically important in that they provide a sheltered habitat for fish, invertebrates, and other marine plants by their ability to moderate the force of waves and currents. In addition, these plants provide a source of energy for the associated biological system, either directly, by providing food for grazing sea

## TABLE 3.1

## KEY RESEARCH PAPERS DEALING WITH MARINE PRODUCTIVITY IN BRITISH COLUMBIA COASTAL WATERS

(Cited in Bibliography)

1. Anita et al. (1962)
2. Borstad, et al. (1980b)
3. Borstad and Brown (1981)
4. Borstad et al. (1981)
5. Denman et al. (1980) Institute of Ocean Sciences (Dept. of Fisheries and Oceans)
6. Dilke et al. (1979) University of British Columbia Dept. of Oceanography - "Ships of Opportunity"
7. Le Brasseur (1965 a&b)
8. Mason et al. (1981) Pacific Biological Station, Nanaimo, B.C.
9. McAllister et al. (1959)
10. McAllister (1962)
11. Parsons (1965)
12. Perry et al. (1981) University of British Columbia Dept. of Oceanography - "Ships of Opportunity"
13. Stephens, K. (1964)
14. Tabata et al. (1961)
15. Trans Mountain Pipe Line Ltd. (1980) Volume XVI Biological Inventory and Volume XVII Map Folio

urchins, or indirectly, by contributing organic carbon and other essential nutrients to the system in general. The marine algae within British Columbia are not yet of major economic importance. However, in other parts of the world they are commonly used as a source of food for humans (e.g. Porphyra in Japan) or as an important source of colloids for industry (e.g. kelp beds in California).

Estuarine areas composed primarily of eelgrass (Zostera sp. and Phyllospadix sp.) and associated salt marsh communities are also very important and sensitive ecological zones. These areas collect and stabilize sediments (by retarding current action), cycle nutrients from the sediments, and serve as a feeding and breeding habitat for shellfish, finfish and marine birds. While living, the plants in these areas actively collect and store various nutrients. Upon their death they release these chemicals into the surrounding water, thereby providing an important source of compounds for the entire community (detritus food chains). Generally, estuarine systems are extremely productive coastal areas which support various commercial fish species and numerous marine birds.

Marine plant resources are illustrated in Figure 3.1. Major scientific papers concerned with the distribution and abundance of marine plants found in the study area are listed below in Table 3.2.

### TABLE 3.2

### KEY RESEARCH PAPERS CONCERNED WITH THE DISTRIBUTION AND ABUNDANCE OF MARINE PLANTS IN BRITISH COLUMBIA COASTAL WATERS

(Cited in Bibliography)

1. Adkins and Stefanson (1979)
2. Austin et al. (1971)
3. Bell and Kallman (1976c)
4. Coon et al. (1977, 1979, 1980)
5. Haegele and Hamey (1977, 1979a, 1979b, 1980)
6. Hawkes et al. (1978)
7. Hoos (1975)
8. Lee and Bourne (1977)
8. Marine Resources Branch (Coon, pers. comm.)
10. Morris and Leany (1980)
11. Odum (1958) in Thayer et al. (1975)
12. Thayer et al. (1975)
13. Trans Mountain Pipe Line Ltd. 1980 Volume XVI Biological Inventory and Volume XVII Map Folio

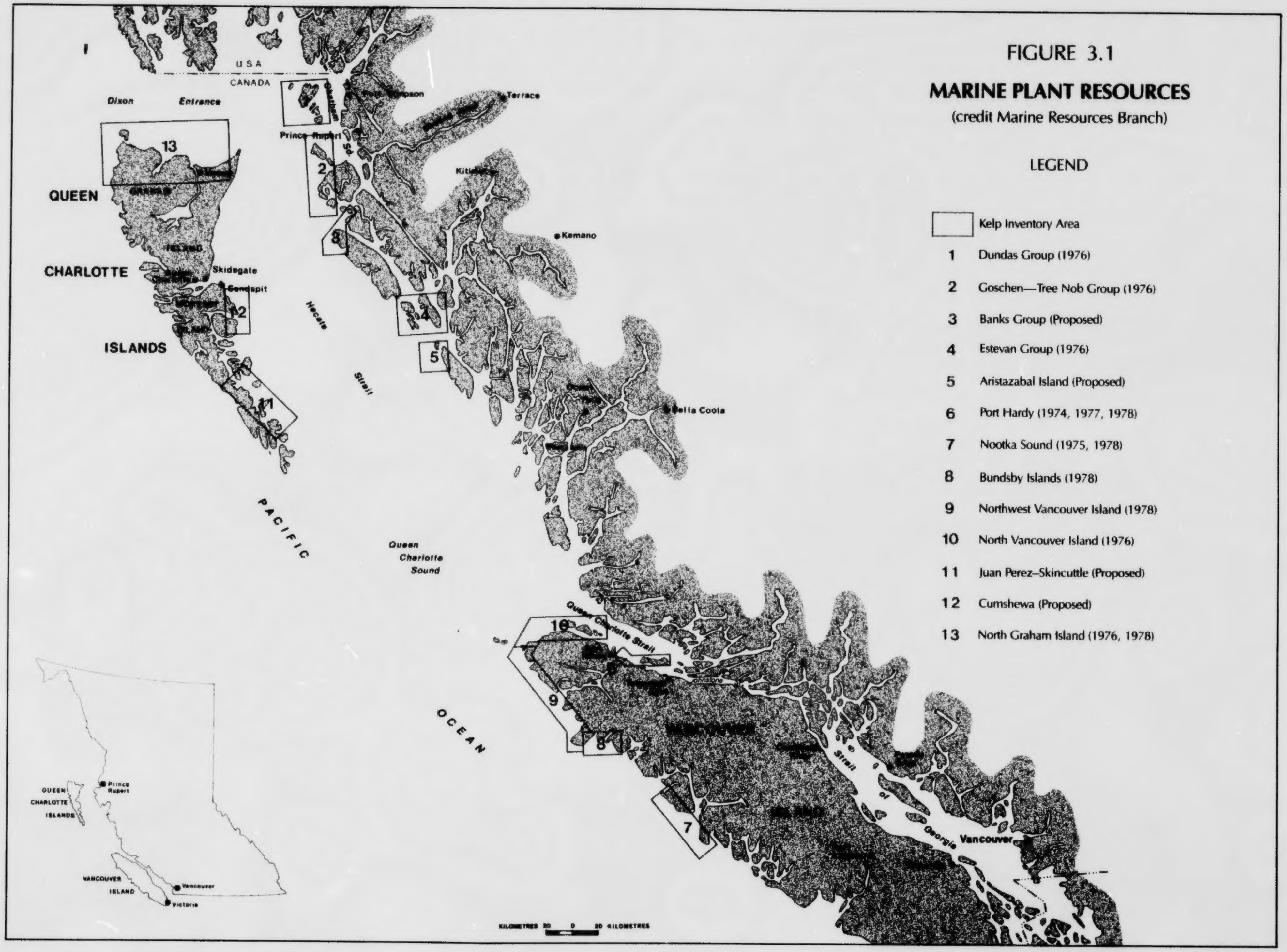

FIGURE 3.1

**MARINE PLANT RESOURCES**

(credit Marine Resources Branch)

LEGEND
▭ Kelp Inventory Area
1 Dundas Group (1976)
2 Goschen—Tree Nob Group (1976)
3 Banks Group (Proposed)
4 Estevan Group (1976)
5 Aristazabal Island (Proposed)
6 Port Hardy (1974, 1977, 1978)
7 Nootka Sound (1975, 1978)
8 Bundsby Islands (1978)
9 Northwest Vancouver Island (1978)
10 North Vancouver Island (1976)
11 Juan Perez–Skincuttle (Proposed)
12 Cumshewa (Proposed)
13 North Graham Island (1976, 1978)
USA
CANADA
Dixon
Entrance
QUEEN
CHARLOTTE
ISLANDS
Skidegate
Sandspit
Prince Rupert
Terrace
Kitimat
Kemano
Hecate
Strait
Bella Coola
PACIFIC
OCEAN
Queen
Charlotte
Sound
Queen Charlotte Strait
Strait
of
Georgia
Vancouver
QUEEN
CHARLOTTE
ISLANDS
Prince
Rupert
VANCOUVER
ISLAND
Vancouver
Victoria
KILOMETRES 20 0 20 KILOMETRES

### 3.2.4 MARINE INVERTEBRATES (See Figure 3.2 a and b)

Marine invertebrates (animals without backbones) are associated with the intertidal area and sea bottom and as such, are often referred to as benthic invertebrates. Several factors determine the habitation of marine benthic invertebrates. They include physical and chemical effects such as sediment grain size, dissolved oxygen, organic content, light, current, dessication, salinity, and exposure and biological effects such as food availability, predation, reproductive strategy and behaviour (Parsons et al., 1977; Tait, 1968).

Marine invertebrate resources considered in this section are limited to those which are commercially valuable or which have commercial potential. They include clams, oysters, geoducks, shrimp, prawns, crabs, scallops, abalone, red sea urchins, octopus, mussels and gooseneck barnacles. Inventory information gathered to date on these species has been largely a result of commercial exploitation or scientific studies in response to this exploitation. Inventory information on non-commercial species is sparse for most of the study area, however, a number of relevant studies dealing with the topic of benthic invertebrate communities have been published, including Ricketts and Calvin, 1968; Kozloff, 1973; Stephenson and Stephenson, 1972; and Miller et al., 1980.

Although inventory information of commercial resources is not complete, knowledge of the biophysical requirements of the various species does allow general statements on species distribution. Short descriptions of habitat requirements of various species are provided below as support for the gaps in the inventory information and for the loss of detail due to large scale mapping (Figure 3.2 a and b).

Red sea urchins and northern abalone are members of the nearshore sublittoral community and are most abundant from 0-15 m. Their distribution along the coast is rather ubiquitous where the substrate is rocky and where

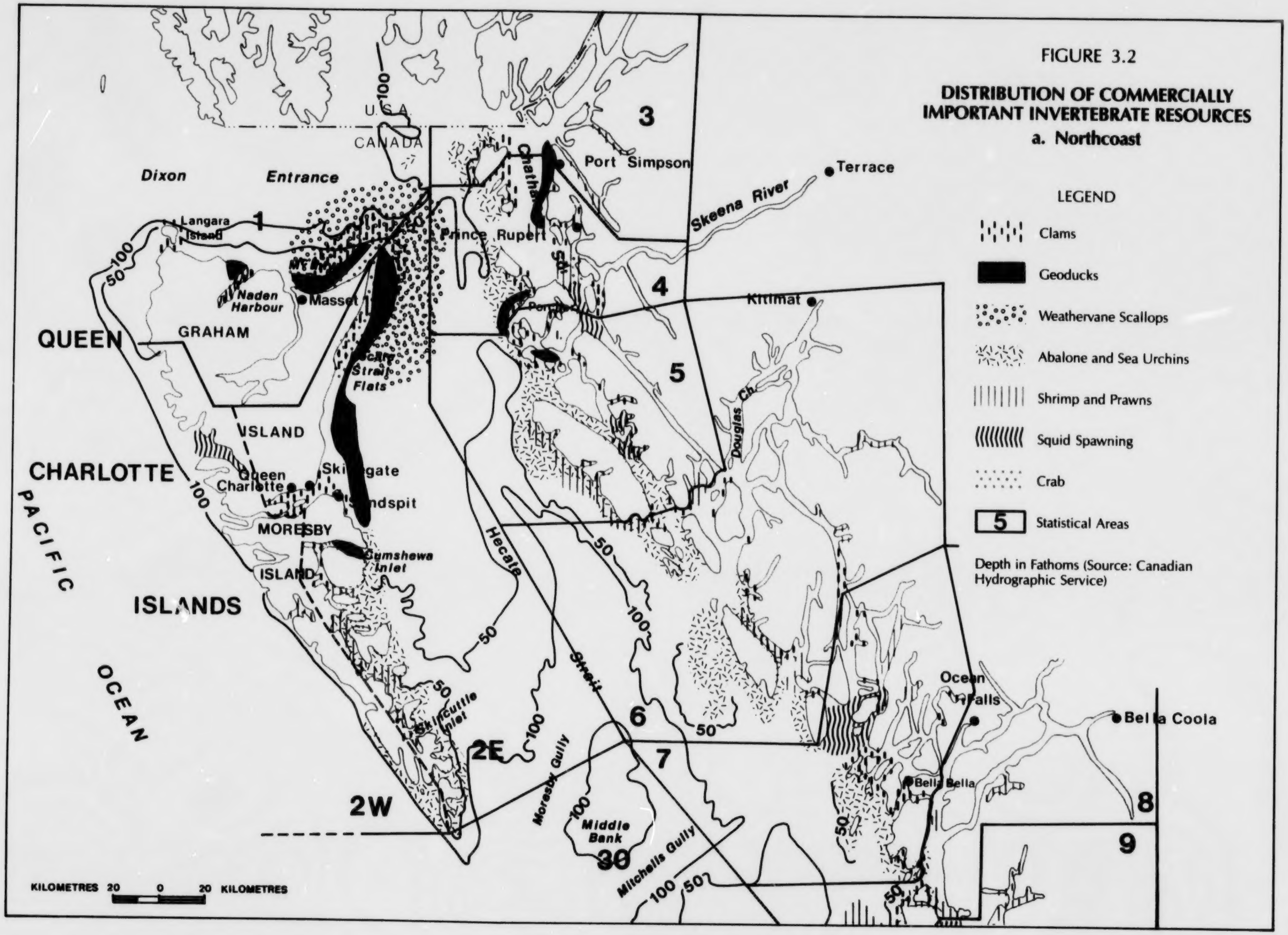

FIGURE 3.2

DISTRIBUTION OF COMMERCIALLY IMPORTANT INVERTEBRATE RESOURCES

a. Northcoast

LEGEND
Clams
Geoducks
Weathervane Scallops
Abalone and Sea Urchins
Shrimp and Prawns
Squid Spawning
Crab
5 Statistical Areas
Depth in Fathoms (Source: Canadian Hydrographic Service)
U.S.A.
CANADA
Dixon
Entrance
Langara Island
Naden Harbour
Masset
GRAHAM
QUEEN
ISLAND
CHARLOTTE
ISLANDS
PACIFIC
OCEAN
Queen Charlotte
Skidegate
Sandspit
MORESBY
ISLAND
Cumshewa Inlet
Skincuttle Inlet
Hecate Strait Flats
Hecate Strait
Prince Rupert
Port Simpson
Chatham Sd.
Skeena River
Terrace
Kitimat
Douglas Ch.
Ocean Falls
Bella Coola
Bella Bella
Moresby Gully
Middle Bank
Mitchells Gully
1
2E
2W
3
4
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7
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9
30
50
100
KILOMETRES 20 0 20 KILOMETRES

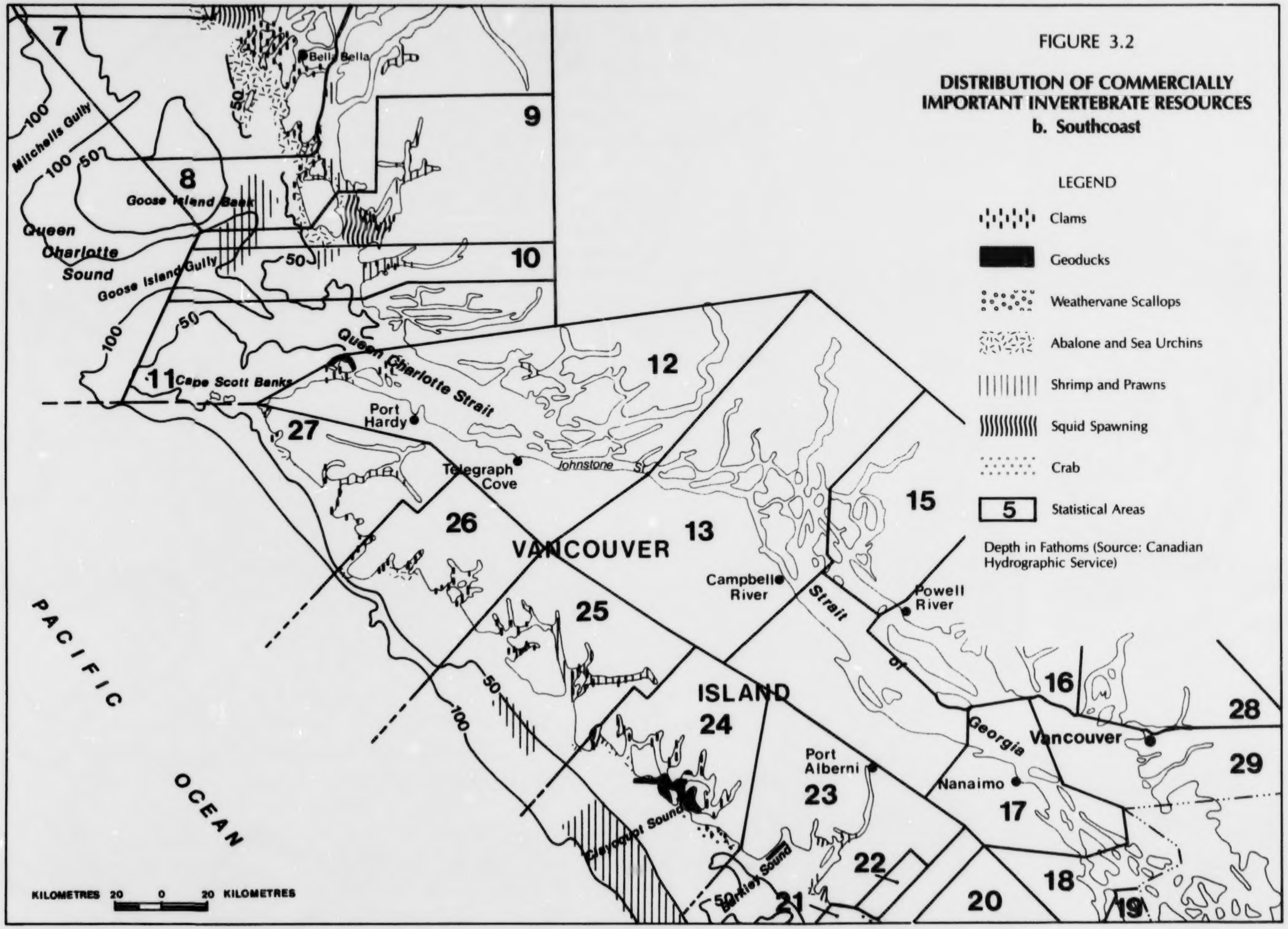

FIGURE 3.2

DISTRIBUTION OF COMMERCIALLY IMPORTANT INVERTEBRATE RESOURCES
b. Southcoast

LEGEND
Clams
Geoducks
Weathervane Scallops
Abalone and Sea Urchins
Shrimp and Prawns
Squid Spawning
Crab
5 Statistical Areas
Depth in Fathoms (Source: Canadian Hydrographic Service)
7
8
9
10
11
12
13
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
Bella Bella
Mitchells Gully
Goose Island Bank
Queen Charlotte Sound
Goose Island Gully
Cape Scott Banks
Queen Charlotte Strait
Port Hardy
Telegraph Cove
Johnstone St.
VANCOUVER ISLAND
Campbell River
Powell River
Strait of Georgia
Vancouver
Nanaimo
Port Alberni
Clayoquot Sound
Barkley Sound
PACIFIC OCEAN
50
100
KILOMETRES 20 0 20 KILOMETRES

there is tidal or wind generated water movement. The location of these species, marked on Figure 3.2 a and b, is general in nature and is not meant to be site-specific.

Two species of mussels are found along the British Columbia rocky intertidal coastline: the California mussel and the edible (blue, bay) mussel. The former is found on exposed coasts while the latter is usually found in more protected waters (Fralick and Tillapaugh, 1979). Their distribution is also ubiquitous, although populations of *Mytilus edulis* may disappear and reappear for reasons as yet unknown (Heritage, pers. comm., 1982).

Shrimp and prawns are harvested from depths ranging from 20 to 250 m. Commercially important concentrations of shimp accumulate in only a few areas: generally on the continental shelf where the bottom is mud or soft sand. As prawns tend to accumulate where the bottom is rocky, many commercial prawn fisheries occur in inlets an bays (Neilson, 1981). A major factor limiting the distribution of these animals is the fact that they do not tolerate strong current (Boutillier, pers. comm., 1982). Exploratory surveys for new shrimp and prawn stocks are ongoing.

Low energy, sand/gravel/shell beaches dispersed throughout the coast provide habitat for commercial hardshell clam populations (e.g., butter clams, native littleneck clams, Japanese littleneck clams [manila clams]). Tidal level and water temperature determine the population distribution of these species. It would be an impossible task to mark all beaches which contain clams, but known commercial clam beaches have been identified (see Figure 3.2). Razor clams commonly inhabit extensive, exposed sandy beaches, the two major populations being found on Rose Spit and Long Beach.

Gooseneck barnacles are an open coast species whose distribution is extensive on rocky intertidal foreshore. Although they are not harvested commercially they have commercial potential. Their total distribution is not indicated on Figure 3.2 because of lack of inventory information.

For ease of presenting inventory information on commercial species (both shellfish and fish) and for comparison purposes between potential hydrocarbon exploration areas, the coast has been divided into 4 major areas:

(I) Dixon Entrance - comprised of Fisheries Statistical Areas 1, 3 and 4 (see Figure 3.3). Although Areas 3 and 4 appear to be somewhat removed from Dixon Entrance, the fishery resources produced from rivers in these areas are largely captured in Dixon Entrance fisheries.

(II) Hecate Strait - comprised of Fisheries Statistical Areas 2E, 5 and 6. Although the southern half of Area 4 could be included as part of Hecate Strait, it is considered part of Dixon Entrance for reasons mentioned in I (above).

(III) Queen Charlotte Sound/Queen Charlotte Strait - Queen Charlotte Sound is comprised of Fisheries Statistical Areas 7-11 inclusive, plus Area 30. Queen Charlotte Strait is included within Area 12; an area generally considered part of Johnstone Strait. A large portion of the salmon produced in rivers emptying into the inside waters funnel northward through Queen Charlotte Strait into Queen Charlotte Sound during their outward migration and return the same way during their spawning migration. For this reason the two statistical areas are combined in this discussion.

(IV) Offshore - comprised of areas outside the Fishing Zone Baselines, this region includes Fisheries Statistical Areas 2 west, 21, and 23-27 inclusive. This is essentially the area offshore from Vancouver Island and the Queen Charlotte Islands.

Inventory information presented here draws heavily upon that prepared by LGL Limited and Environmental Services Limited (ESL) for Trans Mountain Pipe Line Company Limited (TMPL), August 1980 (Volume XVI and the accompanying Map Folio, Volume XVII). Information in the present report is a synthesis of the most current available information including two previous

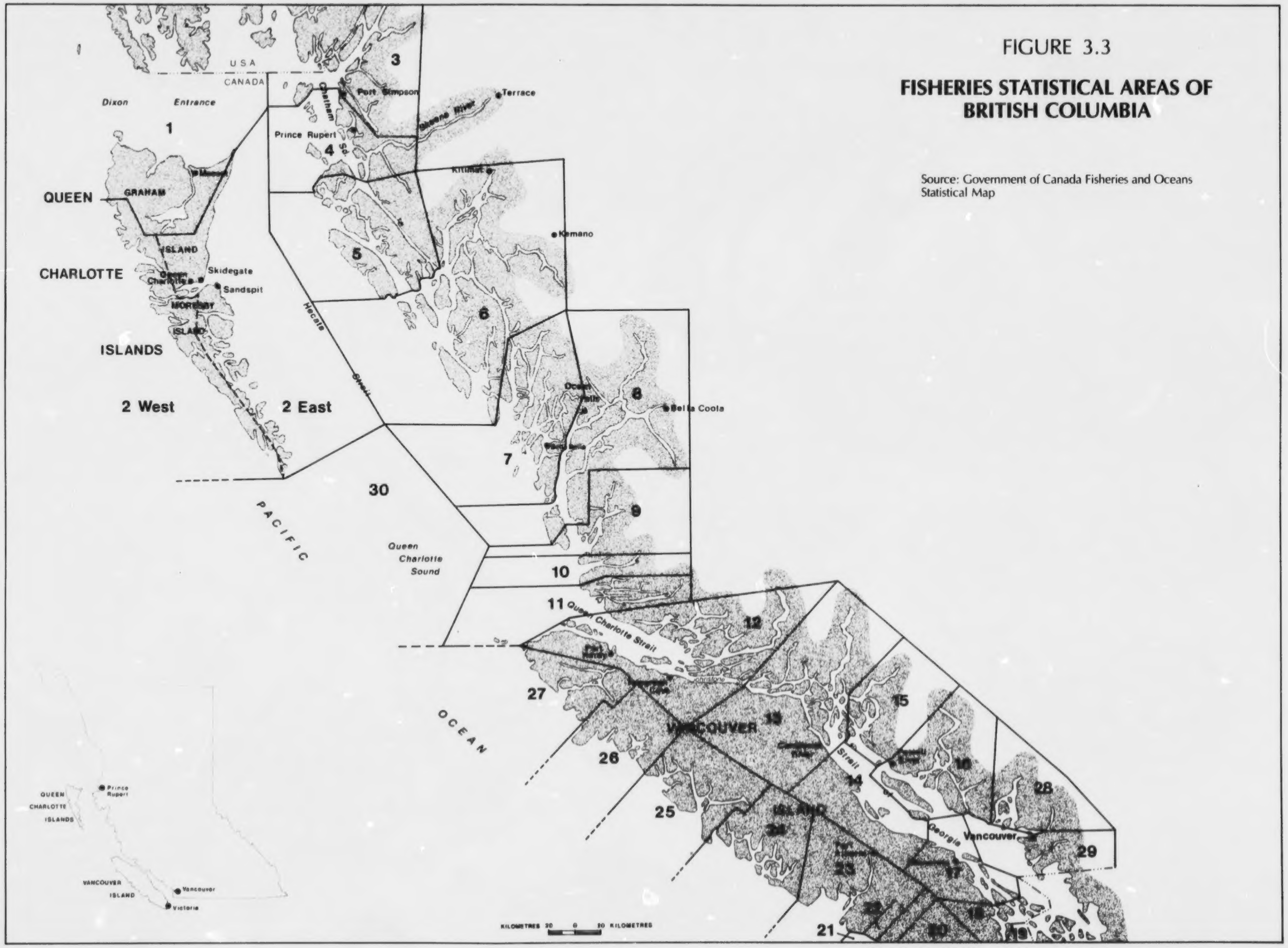
U S A
CANADA
Dixon
Entrance
1
3
Port Simpson
Terrace
Chatham Sd.
Prince Rupert
4
Skeena River
Kitimat
QUEEN
GRAHAM
ISLAND
CHARLOTTE
Queen Charlotte
Skidegate
Sandspit
MORESBY
ISLAND
ISLANDS
5
Kemano
Hecate
Strait
6
2 West
2 East
Ocean Falls
8
Bella Coola
7
30
9
PACIFIC
Queen
Charlotte
Sound
10
11
Queen Charlotte Strait
12
27
OCEAN
VANCOUVER
13
15
26
Strait
14
16
28
25
ISLAND
24
Georgia
Vancouver
29
23
17
22
21
20
18
19
QUEEN
CHARLOTTE
ISLANDS
Prince Rupert
VANCOUVER
ISLAND
Vancouver
Victoria
KILOMETRES 20 0 20 KILOMETRES

FIGURE 3.3

FISHERIES STATISTICAL AREAS OF BRITISH COLUMBIA

Source: Government of Canada Fisheries and Oceans Statistical Map

map series: Oil Spill Countermeasure Map Series (Canada, Department of Environment, Environmental Protection Service, 1976) and West Coast Offshore Environment Map Series (Canada, Department of Environment, Environmental Protection Service, 1978). Fisheries statistics included were obtained from British Columbia Catch Statistics, Department of Fisheries and Oceans.

## I Dixon Entrance

Shellfish resources of Dixon Entrance are mapped on TMPL, 1980, Map C-1. McIntyre Bay is a highly productive area for such commercial species as dungeness crabs, geoducks and weathervane scallops. Rose Spit has the largest of two major concentrations of razor clams on the coast, while mainland beaches are important butter clam harvesting locations. Next to dungeness crabs, clams (razor and butter) are second in terms of landed weight (see Table 3.3). Abalone and sea urchin populations are found in the Dundas Group and off Porcher and Stephens Islands. Locations marked on the map are general and may be slightly inaccurate in some areas.

## II Hecate Strait

Populations of razor clams, geoducks, scallops, and dungeness crabs noted in McIntyre Bay are continuous along the northeast coast of Graham Island into Hecate Strait. Geoducks are found along the entire east coast of Graham Island as well as around Porcher Island. Due to unconsolidated bottom sediments off the east coast of Graham Island, this area is not productive for sea urchins and abalone. Major prawn fishing grounds are noted on Figure 3.2; most of these occur in inlets. Numerous locations of clams have been identified throughout Hecate Strait. Clams, abalone and crabs are the major commercial species harvested in this area (see Table 3.3).

## III Queen Charlotte Sound/Queen Charlotte Strait

The Queen Charlotte Sound/Queen Charlotte Strait region contains important shrimp and prawn populations. Sea urchin and abalone populations are found in some of the more exposed locations on the central coast as well as in Queen Charlotte Strait, although only abalone are commercially harvested.

Clams are harvested in locations throughout the area and represent the major species landed in terms of weight (see Table 3.3). Squid spawning grounds have been identified near the entrance to Rivers Inlet.

## IV Offshore

Inventory information on commercial shellfish resources on the west coast of the Queen Charlotte Islands is sparse. Rennell Sound has been identified as a squid spawning ground and Tasu Sound as a prawn fishing ground. Although no abalone or sea urchin inventory information is available for the west coast of the Queen Charlotte Islands, abalone is fished commercially on the southwest side of Moresby Island and does exist on the remainder of the offshore coast. The populations here, however, may be stunted due to extreme exposure (Breen, pers. comm., 1981).

Geoducks are the major species landed in the Offshore area (see Table 3.3) and while they are taken primarily from Clayoquot Sound some are also from Barkley Sound and Nootka Sound on Vancouver Island. Valuable shrimp grounds are located on the continental shelf off the mouth of these sounds. Eighty percent of the crabs landed in the Offshore area are harvested in Clayoquot Sound.

TABLE 3.3

AVERAGE COMMERCIAL SHELLFISH HARVEST 1978-80 INCLUSIVE
(METRIC TONS)

| Species | Dixon Entrance | Hecate Strait | Queen Charlotte Sound & Strait | Offshore |
|---|---|---|---|---|
| Shrimp and prawns | 23 | 19 | 104 | 521 |
| Clams | 221 | 216 | 208 | 68 |
| Horse Clams | - | - | * | - |
| Geoducks | 1 | 10 | 19 | 1072 |
| Crab | 502 | 179 | 84 | 131 |
| Abalone | 11 | 197 | 26 | * |
| Oysters | - | - | - | 18 |
| Red Sea Urchins | - | - | - | 4 |

* Less than 500 kg
Source: British Columbia Catch Statistics

### 3.2.5 FISH (See also Figure 3.4 a and b, 3.5 a and b)

Inventory information in this section is only for those fish species which sustain major commercial fisheries (ie., salmon, herring, halibut, groundfish). This is because information on their location and relative abundance is available from recorded catch statistics, whereas inventory on non-commercial fish species is non-existent. Species lists for these fish may be available for locations which are under scientific investigation. As in section 3.2.4, information presented here relies heavily on the TMPL (1980) report. Fisheries statistics were compiled from British Columbia Catch Statistics or, in the case of groundfish, from J. Smith (Department of Fisheries and Oceans). It is worth noting that salmon escapement data (presented as an index of relative run strengths in the various areas) are old and do not reflect increases recently seen due to the Salmonid Enhancement Program. The same areas used in the marine invertebrate inventory section (3.2.4) are used here for ease of presentation and comparison (see Table 3.4).

#### I Dixon Entrance

The Skeena River, second only to the Fraser as a salmon producer, empties into the ocean near the confluence of Dixon Entrance and Hecate Strait (i.e., Chatham Sound). Production statistics relating to the Skeena are included in this section because the influence of the Skeena River as a salmon producer is felt mainly in Dixon Entrance [i.e., (1) juvenile salmon generally migrate north once they enter the ocean and (2) the majority of the adult salmon runs returning to the Skeena River come in through Dixon Entrance]. All five species of Pacific salmon occur in this area. Department of Fisheries and Oceans publishes spawning records of major rivers and these have been summarized for each statistical area in Figure 3.3. Important juvenile salmon nursery areas have been identified at Inverness Passage, Flow Bank, DeHorsey Bank and the Skeena River estuary itself (Hoos, 1975; TMPL, 1980a). During 1978-80 salmon landings from Dixon Entrance averaged 9113 mt or 15.4% of the total British Columbia landings.

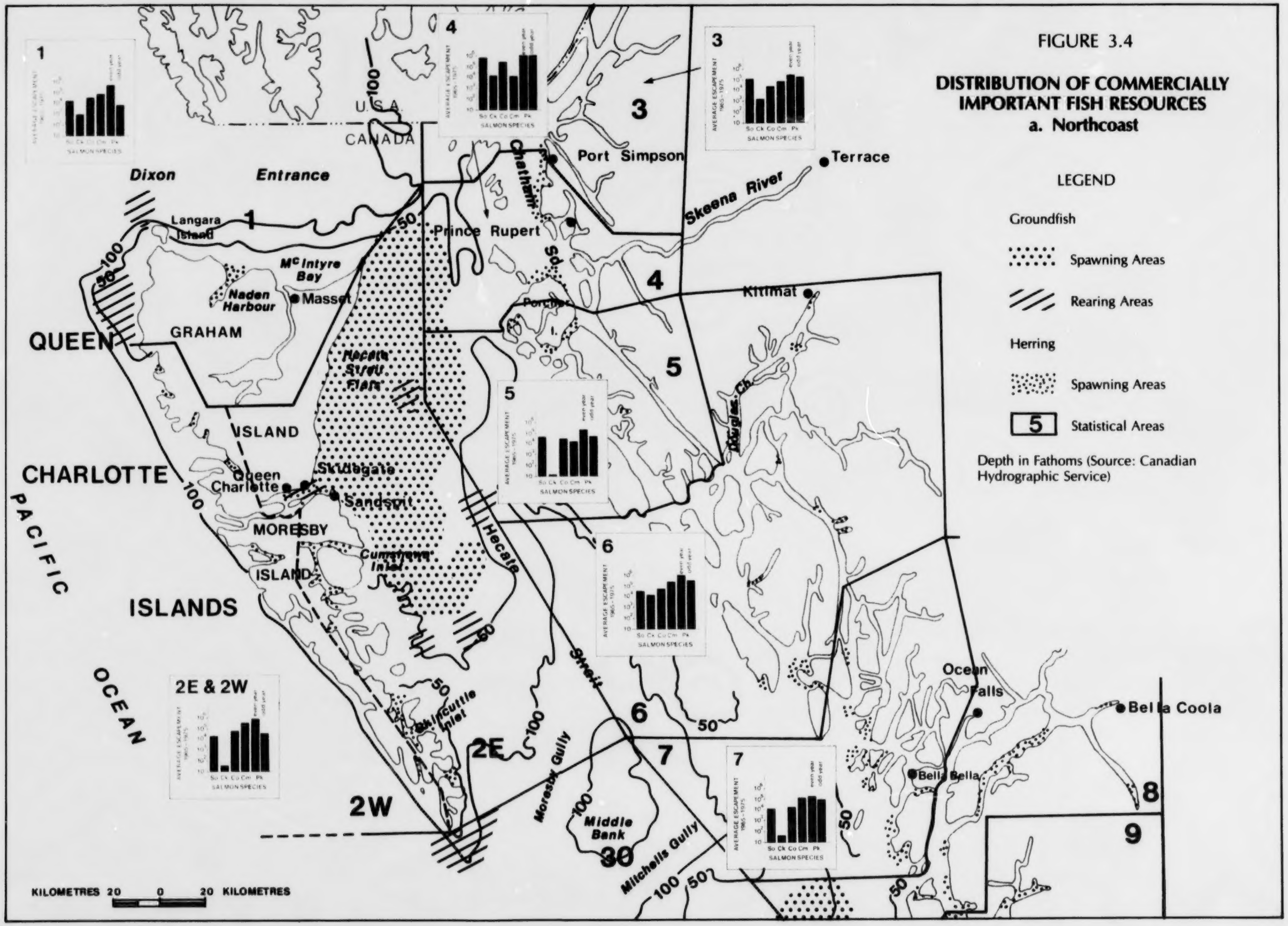

FIGURE 3.4

DISTRIBUTION OF COMMERCIALLY IMPORTANT FISH RESOURCES
a. Northcoast

LEGEND
Groundfish
Spawning Areas
Rearing Areas
Herring
Spawning Areas
5 Statistical Areas
Depth in Fathoms (Source: Canadian Hydrographic Service)
U.S.A.
CANADA
Dixon
Entrance
Langara Island
Mc Intyre Bay
Naden Harbour
Masset
GRAHAM
QUEEN
ISLAND
CHARLOTTE
Queen Charlotte
Skidegate
Sandspit
MORESBY
ISLAND
Cumshewa Inlet
ISLANDS
PACIFIC
OCEAN
Skincuttle Inlet
Hecate Strait Flats
Hecate
Strait
Moresby Gully
Middle Bank
Mitchells Gully
Prince Rupert
Chatham Sd.
Port Simpson
Porcher I.
Skeena River
Terrace
Kitimat
Douglas Ch.
Ocean Falls
Bella Bella
Bella Coola
1
2E & 2W
2E
2W
3
4
5
6
7
8
9
50
100
30
AVERAGE ESCAPEMENT 1965-1975
even year
odd year
So Ck Co Cm Pk
SALMON SPECIES
KILOMETRES 20 0 20 KILOMETRES

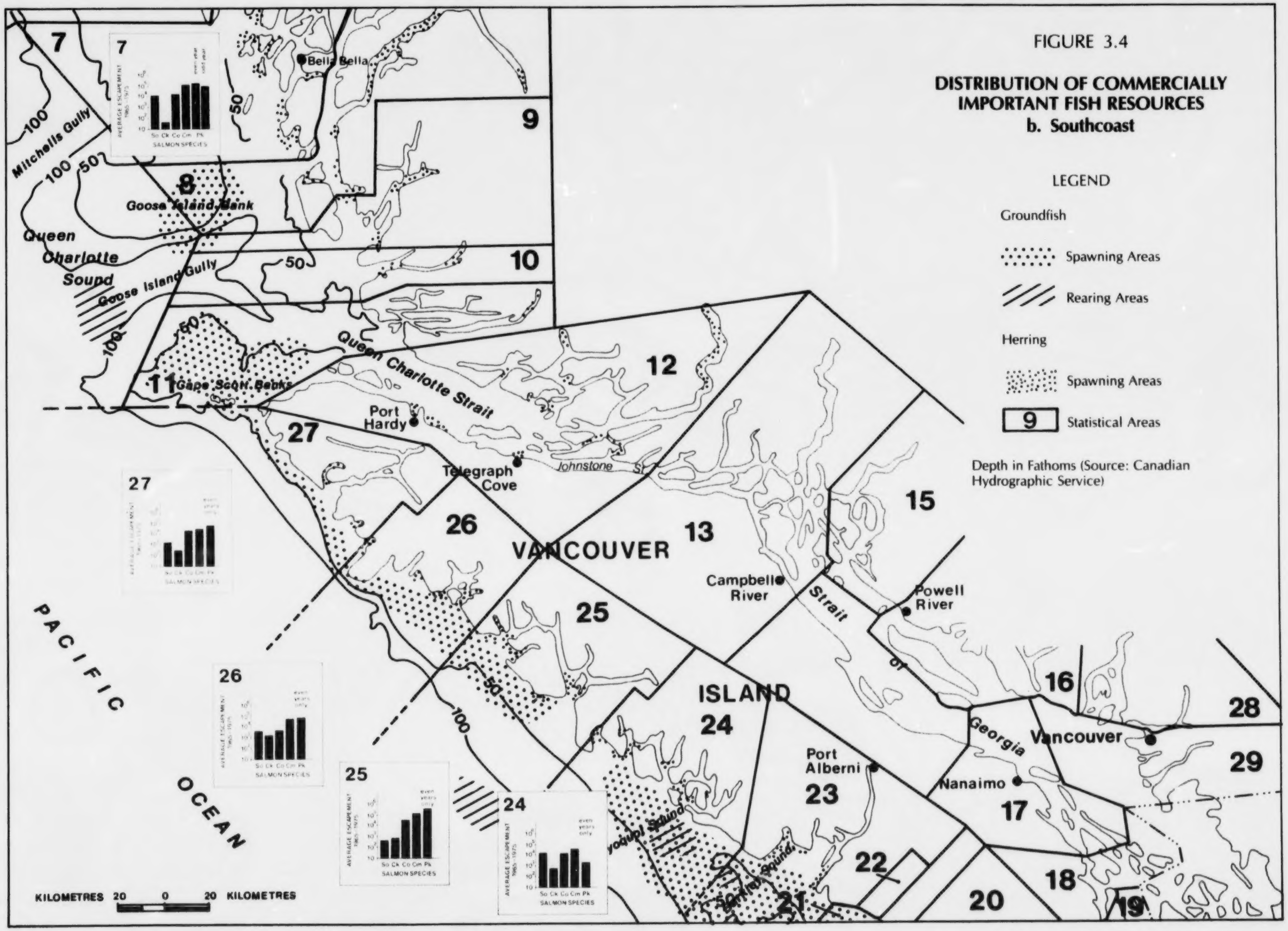

FIGURE 3.4

DISTRIBUTION OF COMMERCIALLY IMPORTANT FISH RESOURCES
b. Southcoast

LEGEND
Groundfish
Spawning Areas
Rearing Areas
Herring
Spawning Areas
9 Statistical Areas
Depth in Fathoms (Source: Canadian Hydrographic Service)
Bella Bella
Mitchells Gully
Goose Island Bank
Queen Charlotte Sound
Goose Island Gully
Cape Scott Banks
Queen Charlotte Strait
Port Hardy
Telegraph Cove
Johnstone St.
VANCOUVER ISLAND
Campbell River
Powell River
Strait of Georgia
Vancouver
Nanaimo
Port Alberni
Nootka Sound
Kyuquot Sound
PACIFIC OCEAN
7
8
9
10
11
12
13
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
50
100
AVERAGE ESCAPEMENT 1965-1975
So Ck Co Cm Pk
SALMON SPECIES
even years only
KILOMETRES 20 0 20 KILOMETRES

## TABLE 3.4

## AVERAGE COMMERCIAL FISH LANDINGS (METRIC TONS) AND PERCENTAGE OF B.C. TOTAL CATCH (BRACKETED)

| | Salmon 1978-80 | Herring 1978-80 | Spawn on Kelp 1978-80 | Halibut 1978-80 | Groundfish 1978-80 |
|---|---|---|---|---|---|
| Dixon Entrance | 9,113 (15.4) | 1,644 (8.3) | 22 (12.8) | 449 (13.3) | 6,342 (21.8) |
| Hecate Strait | 6,906 (11.7) | 11,959 (23.9) | 110 (64.0) | 1,070 (31.8) | 5,105 (17.4) |
| Queen Charlotte Strait | 9,500 (16.1) | 4,018 (8.0) | 5 (2.9) | 345 (10.2) | 6,780 (23.8) |
| Offshore | 12,761 (21.6) | 17,184 (34.4) | - | 329 (9.8) | 6,955 (24.4) |
| Total B.C. Catch | 59,089 | 50,007 | 172 | 3,368 | 28,623 |

Source: B.C. Catch Statistics and J. Smith, Dept. of Fisheries and Oceans.

Naden Harbour is the major herring spawning area in Dixon Entrance. Landings from the herring fishery averaged 1644 mt (1978-80 inclusive) or 3% of the total British Columbia herring landings. Commercial herring spawn-on-kelp operations located in Dixon Entrance accounted for 13% of the British Columbia total spawn-on-kelp harvest for the same three-year period. The average halibut catch in Dixon Entrance during 1978-80 was 449 mt or 13% of the total for British Columbia.

Major groundfish fisheries occur off Langara Island, Tow Hill, Dundas Island and on Two Peaks Ground. In terms of landed weight, the most important groundfish species are pollock and dover sole. There are no known groundfish spawning areas in Dixon Entrance. Groundfish landings from Dixon Entrance over the last 5 years (1976-80 inclusive) averaged 6342 mt or 21.8% of the total catch for British Columbia (J. Smith, pers. comm., 1981).

### II Hecate Strait

All five species of Pacific salmon are produced in the rivers and streams which empty into Hecate Strait. Average spawning escapments for Federal Statistical Areas 5 and 6 are given on Figure 3.4a. Juvenile salmon are found in most nearshore waters during spring and summer. They migrate gradually northward and move farther offshore as they grow. Commercial landings of salmon from Hecate Strait averaged 6909 mt or 11.7% of the total British Columbia salmon landings during 1978-80.

Major herring spawning grounds are found on the east coasts of Graham and Moresby Islands. They include Skidegate, Cumshewa, and Skincuttle Inlets. Other major spawning areas are found on the east side of Hecate Strait in the Douglas Channel and central coast areas. Herring landings for the years 1978-80, averaged 11,959 mt or 23.9% of the total British Columbia landings. The herring spawn-on-kelp industry in Hecate Strait produced 64.0% of the total British Columbia production during the same three years.

Hecate Strait is the most important of the four study areas in terms of halibut fishing. A three year average (1975-80) of 1070 mt or 32% of the total British Columbia catch was landed from Hecate Strait grounds. This was more than double the next most important area (Dixon Entrance). The Hecate Strait flats are an extremely important nursery area for all commercially valuable flatfish, including halibut. This area, which is west of the 30 fathom edge (contour), represents two-thirds of the total area of Hecate Strait (Westrheim, pers. comm., 1981).

Hecate Strait is a major groundfish fishing area with a number of productive fishery banks and one major gully. Major species caught include Pacific cod, walleye pollock, Pacific ocean perch, English sole, rock sole and arrowtooth flounder. The area has accounted for 5105 mt (17.4%) of the annual British Columbia groundfish catch during 1976-80 (J. Smith, pers. comm., 1981). Groundfish spawning areas are not well documented; however, those which have been identified are marked on Figure 3.4a. English sole are thought to spawn in segmental populations throughout the Strait and recruit to the Hecate Strait flats as larvae. These flats are an important rearing habitat for juvenile flatfish (mentioned above) and for juvenile blackcod. Methods of recruitment of flatfish larvae to this area are not known (Westrheim, pers. comm., 1981).

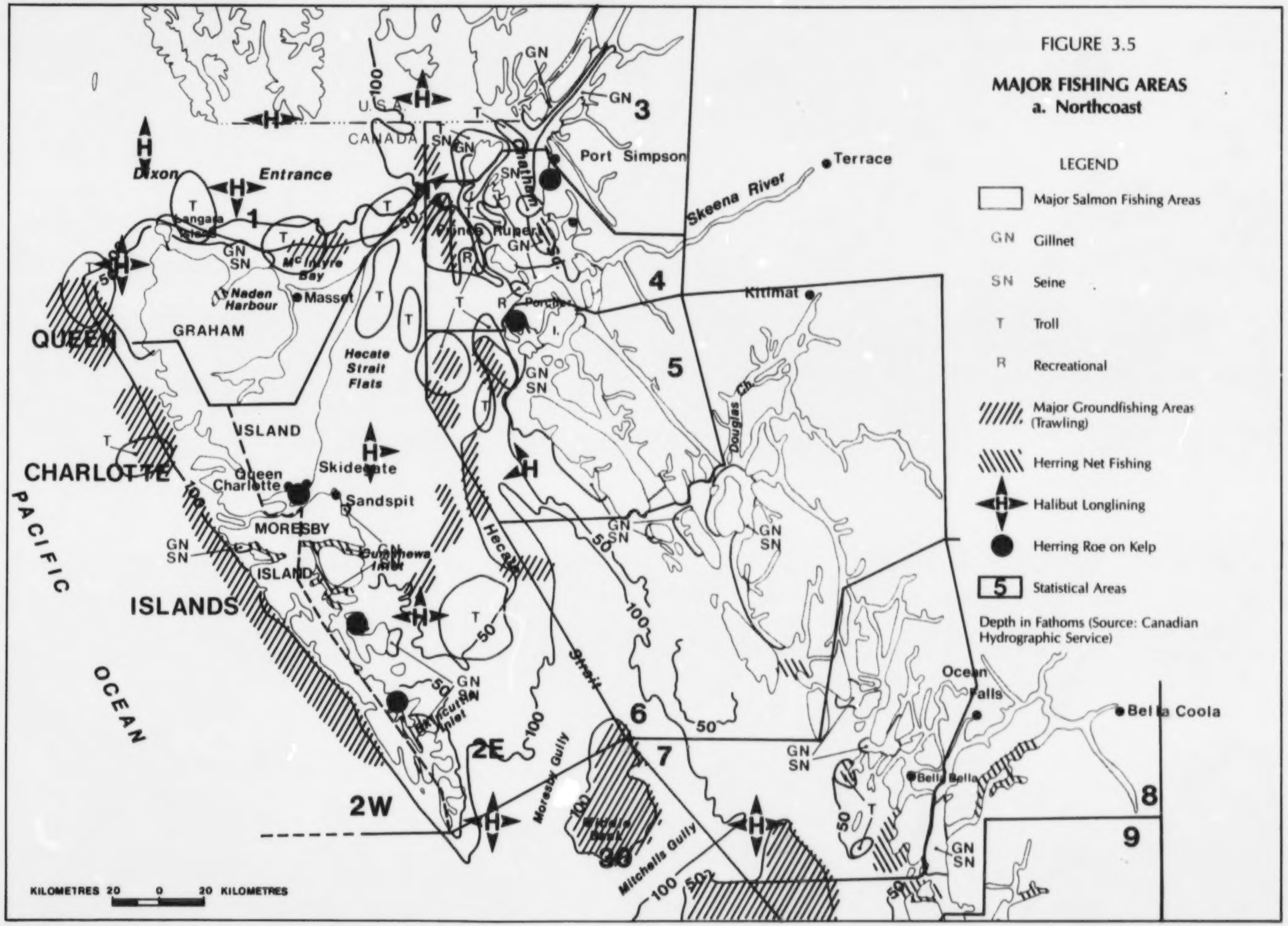

FIGURE 3.5

**MAJOR FISHING AREAS**
**a. Northcoast**

LEGEND
Major Salmon Fishing Areas
GN Gillnet
SN Seine
T Troll
R Recreational
Major Groundfishing Areas (Trawling)
Herring Net Fishing
Halibut Longlining
Herring Roe on Kelp
5 Statistical Areas
Depth in Fathoms (Source: Canadian Hydrographic Service)
U.S.A.
CANADA
Dixon Entrance
Langara Island
McIntyre Bay
Naden Harbour
Masset
GRAHAM
QUEEN
ISLAND
CHARLOTTE
ISLANDS
Queen Charlotte
Skidegate
Sandspit
MORESBY
ISLAND
Cumshewa Inlet
Barrcuffin Inlet
PACIFIC
OCEAN
Hecate Strait Flats
Hecate Strait
Moresby Gully
Mitchells Gully
Chatham Sd.
Port Simpson
Prince Rupert
Porcher I.
Skeena River
Terrace
Kitimat
Douglas Ch.
Ocean Falls
Bella Coola
Bella Bella
1
2E
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50
100
KILOMETRES 20 0 20 KILOMETRES

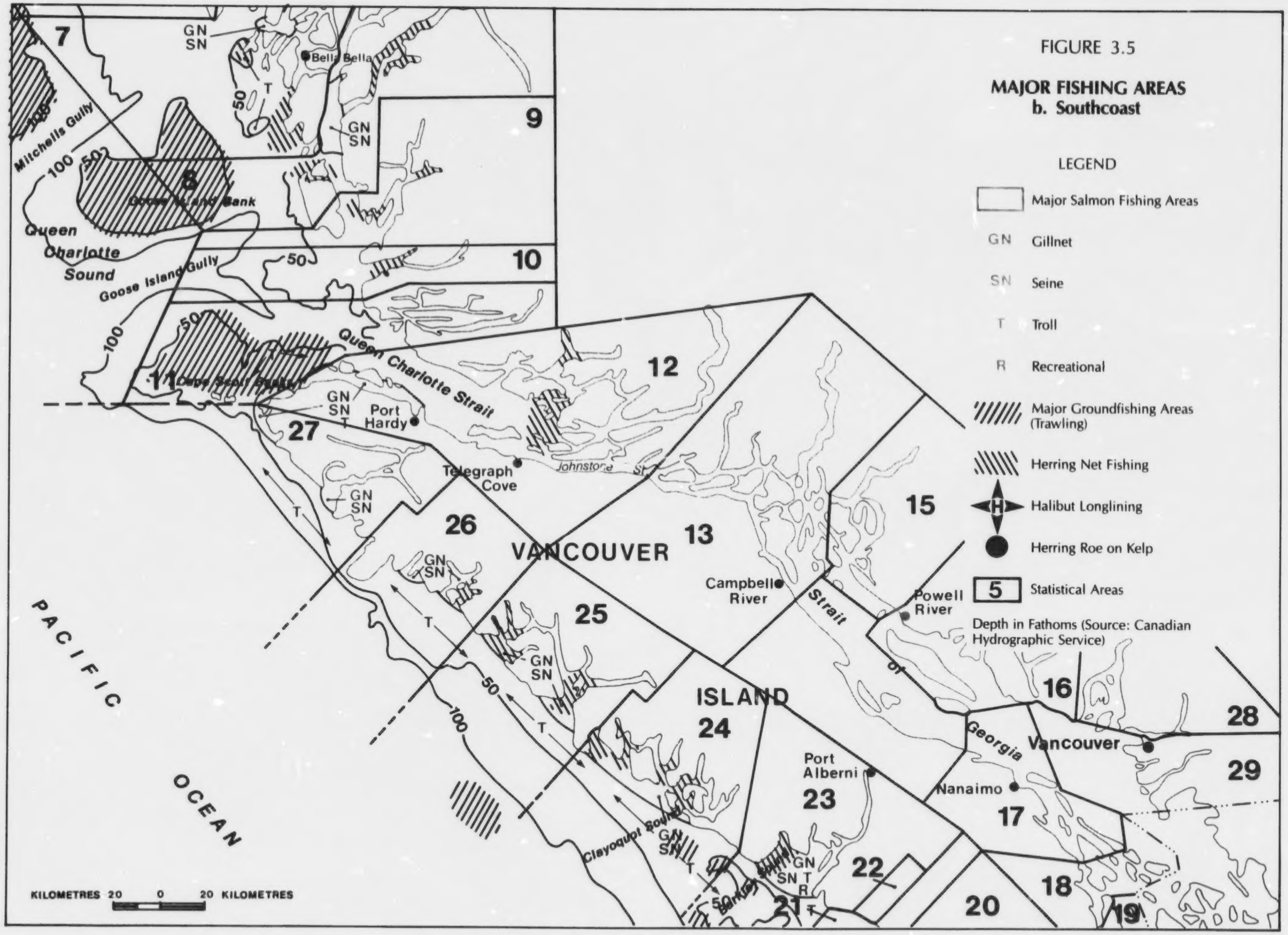


FIGURE 3.5

**MAJOR FISHING AREAS**
**b. Southcoast**

LEGEND
▭ Major Salmon Fishing Areas
GN Gillnet
SN Seine
T Troll
R Recreational
▨ Major Groundfishing Areas (Trawling)
▨ Herring Net Fishing
H Halibut Longlining
● Herring Roe on Kelp
5 Statistical Areas
Depth in Fathoms (Source: Canadian Hydrographic Service)
7
8
9
10
11
12
13
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
GN
SN
T
Bella Bella
Mitchells Gully
Goose Island Bank
Queen Charlotte Sound
Goose Island Gully
Cape Scott Banks
Queen Charlotte Strait
Port Hardy
Telegraph Cove
Johnstone St.
VANCOUVER ISLAND
Campbell River
Powell River
Strait of Georgia
Vancouver
Nanaimo
Port Alberni
Clayoquot Sound
Barkley Sound
PACIFIC OCEAN
50
100
KILOMETRES 20 0 20 KILOMETRES

## III Queen Charlotte Sound/Queen Charlotte Strait

Major salmon fisheries in this area occur in the coastal inlets, (e.g., Rivers Inlet, Hakai Pass). Salmon landings averaged 16% of the British Columbia total or 9500 mt during 1978-80. Queen Charlotte Strait acts as a funnel for juvenile salmon leaving the waters inside Vancouver Island and for adult salmon returning. Juvenile salmon are found in nearshore waters during spring and summer, migrating northward and moving gradually offshore as they grow. Average adult escapements to the rivers in this region are graphed on Figure 3.4.

Herring spawning locations in Queen Charlotte Sound are identified on Figure 3.4a. This area is less important for herring than are the Hecate Strait and Offshore study areas. Herring fishery landings for 1978-80 averaged 4018 mt or 8% of the total British Columbia landings. Herring spawn-on kelp-operation accounted for 2.9% of the British Columbia total. Halibut landings from this region accounted for 10% of the British Columbia total or an average of 345 mt annually (figures based on 1978-80 data).

The Queen Charlotte Sound area has many highly productive groundfish fishing areas. The gullies (i.e., Mitchell's, Goose Island) sustain important fisheries for rockfish (e.g., Pacific ocean perch) while the banks (i.e., Middle, Goose Island, Cape Scott) sustain important fisheries for Pacific cod, halibut and other flatfish. This area produced 23.9% (6780 mt) of the total British Columbia groundfish catch during 1976-80. Certain areas of the banks are also important as spawning and juvenile rearing areas (Westrheim, pers. comm., 1981).

## IV Offshore

Salmon catches in the Offshore area during 1978-80 averaged 12761 mt or 21.6% of the total British Columbia salmon catch. The west coast troll fisheries accounted for a major proportion of the catch.

The highly productive upwelling areas off west coast Vancouver Island (e.g., Barkley Sound) are important rearing areas for juvenile salmon. It is thought that a portion of the Georgia Strait coho stocks stop at these rich feeding grounds during their ocean migration period (Godfrey et al., 1975).

Herring landings from the Offshore area during 1978-80 accounted for a major portion of the British Columbia landings [i.e., 17184 mt (average) or 34.4% of British Columbia total]. Major fisheries occur in Barkley and Clayoquot Sounds. Spawning grounds and roe herring fishery locations are identified in Figure 3.4a and b and Figure 3.5a and b. To date, no herring spawn-on-kelp operations have occurred in this area.

Halibut landings from the Offshore area account for 10% of the British Columbia total or 329 mt per year based on a three year average (1978-80). The major groundfish fisheries in the Offshore areas are for Pacific cod, lingcod, rockfish and blackcod. A fishery for hake has recently begun, with catches of 26000 mt (out of a total allowable catch of 35000 mt) being reported. Groundfish catches for this area have averaged 6955 mt or 24.4% of the total 1978-80 British Columbia groundfish catch (excluding hake).

### 3.2.6 MARINE BIRDS

The marine waters of British Columbia's coast are important to several millions of breeding, migrating, and resident water birds. It is estimated that one million migrant birds alone, including arctic loons, phalaropes, geese, swans, grebes, brants, gulls, ducks and shearwaters use these waters as temporary stop-over sites to rest and feed during their spring and fall migrations. Although these marine birds occur along the entire coastline, they are particularly abundant in protected estuaries, bays, onshore nesting sites and offshore feeding areas. In addition, there are a large number of permanent resident shore-associated species including oyster catchers, bald eagles, peregrine falcons, great blue herons, ospreys, kingfishers and northwestern crows.

Various government agencies (e.g., Provincial Museum of British

Columbia, and British Columbia Ministry of Environment Fish and Wildlife Branch) have compiled maps showing the location and population estimates of marine-associated, breeding birds on the Queen Charlotte Islands and Vancouver Island. Their general findings are as follows:

i) The Scott Islands group on the northwest tip of Vancouver Island (including Triangle Island) has the largest colony of Cassin's auklets in the study area; an estimated 40% of the world breeding population of this bird. The largest breeding colony of tufted puffins on Canada's Pacific coast occurs in this island group, as well as a large number of rhinoceros auklets

ii) On the east coast of Moresby Island there are major nesting areas for storm-petrels, Cassin's auklets, and one especially large colony of ancient murrelets on Dodge Point, Lyell Island

iii) In the South Moresby area, there are major nesting colonies of Cassin's auklets at Kerouard and Anthony Islands. Both of these islands are ecological reserves. The Engelfield Bay area is important for storm petrel breeding as well as for other sea birds

iv) Along the west coast of Graham Island, both Hippa Island (an ecological reserve) and Frederick Island are major nesting sites for Cassin's auklets and ancient murrelets. Lepas Bay, also an ecological reserve, is an important petrel nesting area

v) Langara Island, on the northwest tip of Graham Island, has a large colony of ancient murrelets

vi) On the west coast of Vancouver Island there are marine bird nesting colonies in Barkley Sound, Clayoquot Sound, and Kyuquot Sound

vii) In Queen Charlotte Strait there is a large colony of rhinoceros auklets on Pine Island and colonies of petrels on Tree Island and in the Buckle Group

viii) In the northern mainland coast area there is a large colony of rhinoceros auklets on Lucy Island in Chatham Sound, a large colony of Leach's storm petrels on Moore Island, and a colony of ancient murrelets on Byers Island. Both Byers and Moore Islands are ecological reserves

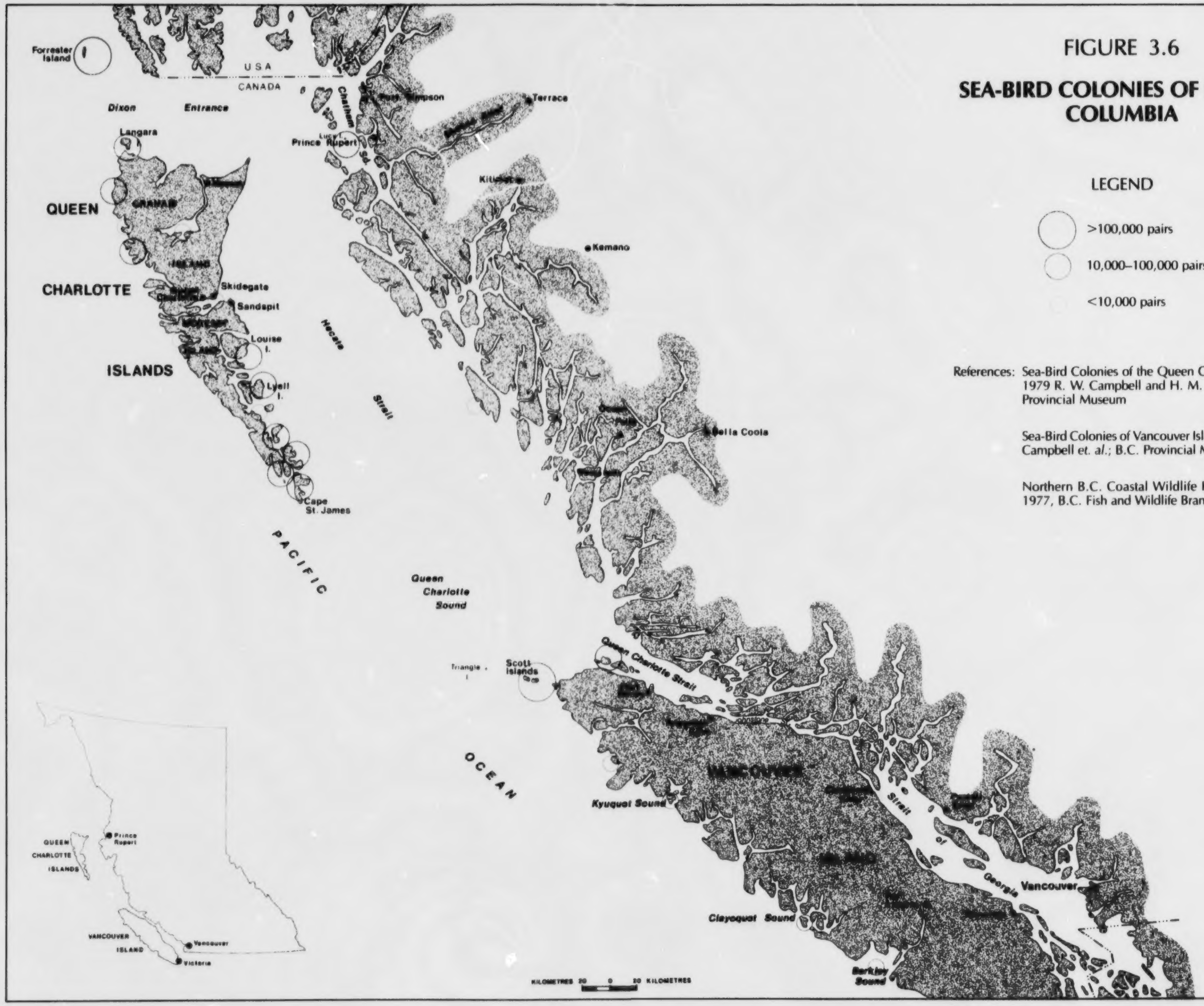
ix) The Forrester Island group in the Alaskan waters of northern Dixon Entrance has large bird nesting colonies supporting over one half million pairs of nesting birds

These data are presented in Figure 3.6 and in Table 3.5. Some general references dealing with various aspects of the bird populations along the coast of British Columbia are listed in Table 3.6.

In summary, there are millions of marine birds in British Columbia that rely on nearshore and offshore habitat for feeding and breeding. The locations of breeding colonies are fairly well documented, although some of the population estimates may be low; perhaps by an order of magnitude (Laszlo Retfalvi, pers. comm., 1981). A great deal of information concerning marine birds remains unknown. Two important concerns which should be addressed before offshore drilling is allowed to proceed are:

1) the exact location and size of offshore feeding grounds for pelagic species;

2) the effect that a major oil spill (or numerous small oil spills) would have on populations of various species. Of particular concern would be those species which have extremely low reproductive rates. Here, a distinct possibility of extinction could exist if the effect of numerous, small oil spills proves to be cumulative and if the reproductive rate is inadequate to replace lost individuals.


Forrester Island
U.S.A.
CANADA
Dixon
Entrance
Langara
QUEEN
CHARLOTTE
ISLANDS
GRAHAM
ISLAND
Skidegate
Sandspit
MORESBY
ISLAND
Louise I.
Lyell I.
Cape St. James
Hecate
Strait
Chatham
Sd.
Port Simpson
Prince Rupert
Terrace
Kitimat
Kemano
Bella Coola
PACIFIC
OCEAN
Queen Charlotte Sound
Triangle I.
Scott Islands
Queen Charlotte Strait
VANCOUVER
Kyuquot Sound
Strait of Georgia
Vancouver
Clayoquot Sound
Barkley Sound
QUEEN CHARLOTTE ISLANDS
Prince Rupert
VANCOUVER ISLAND
Vancouver
Victoria
KILOMETRES 20 0 20 KILOMETRES

## FIGURE 3.6

## SEA-BIRD COLONIES OF BRITISH COLUMBIA

LEGEND

○ >100,000 pairs

○ 10,000–100,000 pairs

○ <10,000 pairs

References: Sea-Bird Colonies of the Queen Charlotte Islands 1979 R. W. Campbell and H. M. Garrioch; B.C. Provincial Museum

Sea-Bird Colonies of Vancouver Island 1976 R. W. Campbell *et. al.*; B.C. Provincial Museum

Northern B.C. Coastal Wildlife Resources Map 1977, B.C. Fish and Wildlife Branch

# TABLE 3.5

# A SUMMARY OF PAIRS OF BREEDING SEABIRDS

| | Scott Islands[1] | Queen Charlotte Strait[1] | West Coast of Vancouver Island[1] |
|---|---|---|---|
| FTSP | | 2700 | 405 |
| LESP | | 12,350 | 12,950 |
| PECO | 50 | 128 | 1260 |
| GWGU | 250 | 629 | 6835 |
| COMU | 2625 | 214 | 8 |
| PIGU | 125 | | 533 |
| ANMU | | | |
| CAAU | 360,000 | 2000 | 325 |
| RHAU | 10,000 | 17,785 | 650 |
| TUPU | 20,000 | | 3126 |
| Total: | 393,050 | 35,806 | 26,092 |

| | Langara Island[4] | West Coast of Graham Island[4] | West Coast of Moresby Island[4] |
|---|---|---|---|
| FTSP | | 11,600 | 9450 |
| LESP | | 10,500 | 25,700 |
| PECO | 72 | 99 | 72 |
| GWGU | 126 | 457 | |
| COMU | | | 50 |
| PIGU | 80 | 160 | 250 |
| ANMU | 25,000 | 51,000 | 10,550 |
| CAAU | | 76,550 | 55,060 |
| RHAU | | 200 | 3025 |
| TUPU | | 300 | 3195 |
| Total: | 25,278 | 150,866 | 107,352 |

| | East Coast of Moresby Island[4] | Northern Mainland Coast[2] | Forrester Island (Alaska)[3] |
|---|---|---|---|
| FTSP | 29,560 | 1015 | 19,350 |
| LESP | 14,540 | 6070 | 344,700 |
| PECO | 185 | 142 | 96 |
| GWGU | 751 | | 400 |
| PIGU | 467 | 80 | 185 |
| ANMU | 121,830 | 7000 | 30,000 |
| CAAU | 26,070 | 862 | 33,870 |
| RHAU | 300 | 28,600 | 54,015 |
| TUPU | 25 | 45 | 41,850 |
| Total: | 193,728 | 43,814 | 524,466 |

| | | | |
|---|---|---|---|
| FTSP | Fork-tailed storm petrel | PIGU | Pigeon guillemot |
| LESP | Leach's storm petrel | ANMU | Ancient murrelet |
| PECO | Pelagic cormorant | CAAU | Cassins auklet |
| GWGU | Glaucous-winged gull | RHAU | Rhinoceros auklet |
| COMU | Common murre | TUPU | Tufted puffin |

[1] B.C. Provincial Museum, 1976

[2] B.C. Fish and Wildlife Northern B.C. Coastal Wildlife Map, 1977

[3] Catalog of Alaskan Seabird Colonies, Fish and Wildlife Service, U.S. Dept. of Interior, 1978

[4] B.C. Provincial Museum, 1979

## TABLE 3.6

## GENERAL REFERENCES ON MARINE BIRDS OF BRITISH COLUMBIA

1. A detailed map prepared by the British Columbia Ministry of Environment, Fish and Wildlife Branch (1977), shows the locations and population estimates (where available) of breeding, migrating, and overwintering marine bird populations for the north coast area (Queen Charlottes and mainland B.C.) and the south coast area (Vancouver Island and mainland B.C.).

2. The Environmental Protection Service of Environment Canada (1978) has prepared a series of maps of the marine offshore environment, one of which gives a general outline of the winter and summer ranges of marine birds along with an oil pollution sensitivity index for the various marine bird groups.

3. The Terrestrial Studies Branch of the British Columbia Ministry of Environment (unpublished) has conducted shoreline bird inventory for much of coastal B.C. and has compiled data for all major marine bird inventory surveys conducted in British Columbia. The British Columbia Provincial Museum (Ministry of Provincial Secretary and Government Services) is interested in marine bird populations from a natural history viewpoint. They are the only agency to collect bird inventory information through voluntary contributions by naturalists. Most of the marine bird inventory information in the files of the British Columbia Provincial Museum and the Terrestrial Studies Branch has not yet been analyzed. In order for this information to be useful in determining the locations and movement of marine bird populations, the data will have to be interpreted. Only then will data gaps become apparent. The Canadian Wildlife Service is responsible for migratory birds, and in conjunction with the Fish and Wildlife Branch of the B.C. Ministry of Environment, sets hunting limits on migratory birds.

4. Savard (1979) surveyed the marine bird population of the open waters of Dixon Entrance, the northern shoreline of Graham Island, the shoreline and open waters of Hecate Strait, as well as Chatham Sound. Skidegate Inlet and Kitkatla Inlet were surveyed. Ground surveys of Graham Island shore were also conducted.

5. Vermeer and Campbell (in prep.) have prepared a marine bird atlas for the British Columbia coast. The report shows distribution and density of several marine bird groups within the study area.

### 3.2.7 MARINE MAMMALS

The following section describes pertinent aspects of the distribution, life history, and migration habits of marine mammals commonly found in British Columbia's coastal waters.

#### Pinnipeds

i) The Northern Fur Seal

Northern fur seals breed in the Pribilof Islands (Alaska) from May to July. About 1.5 million animals migrate past the coast of British Columbia toward California in the fall and winter and return in the spring. During this migration individuals are widely scattered; their route lying from 32 to 800 km off the coast of British Columbia. The fur seal is hunted on the Pribilof Islands by Russia, Japan, and the U.S.A. (M. Bigg, pers. comm., 1981).

ii) Harbour Seal

Harbour seals are distributed throughout British Columbia's marine waters, breeding over their entire range rather than in specific rookeries. Pups are born from May to late June in the Skeena River Estuary and from late June to early September in southeastern Vancouver Island and the adjacent mainland (Bigg, 1969; Fisher, 1952 cited in TMPL, 1980). Pups take to the water almost immediately and in some cases are even born in the water (Bigg, pers. comm., 1981).

iii) Northern Elephant Seal

This seal occurs rarely in British Columbia waters. Only 54 sitings were made from 1958 to 1968: most in Hecate Strait and off the west coast of Vancouver Island (Pike and MacAskie, 1969; cited in TMPL, 1980).

iv) Steller Sea Lion

The B.C. Coastal Wildlife Resources Maps (1977) and Figure 3.7 show the locations of Steller sea lion rookeries and haulouts in B.C. Breeding occurs only at the rookeries located in the Scott Island group (N.W. tip of Vancouver Island), on Kerouard Island (southern tip of Queen Charlotte Islands), and on North Danger Rocks (west of Banks Island, Hecate Strait) (Figure 3.7). The young are born during the summer and begin swimming at about two months. (Bigg, pers. comm., 1981). After breeding, the bulls move to favoured haulouts along the west coast of Vancouver Island, the Queen Charlotte Islands, and the adjacent mainland (TMPL, 1980a).

v) California Sea Lion

The majority of California sea lions do not proceed any farther north than the southern waters of B.C., although some individuals have been sited at Cape St. James and in Alaska. From October to May, males are found at traditional haulouts near southern Vancouver Island (see Figure 3.7).

## Sea Otter

Sea otters were hunted to extinction in Canada in the 19th Century, though populations remained in California and Alaska. In 1969 sea otters were reintroduced to the west coast of Vancouver Island. A small population of about one hundred is now established near Bunsby Island and Bajo Point on the northwest coast of Vancouver Island.

## Cetaceans

Of the twenty species of whales, porpoises and dolphins that are known to occur on Canada's Pacific coast, eleven occur here only rarely. They are listed in Table 3.7. The following is a brief discussion of the cetaceans which occur more commonly in British Columbia. Except where noted, the descriptions are from TMPL, 1980.

i) Sperm Whale

These whales concentrate in pelagic waters in groups of 15 to 30 females. While females are usually not found beyond 50°N. latitude, individuals or small groups of males may be, from May to September.

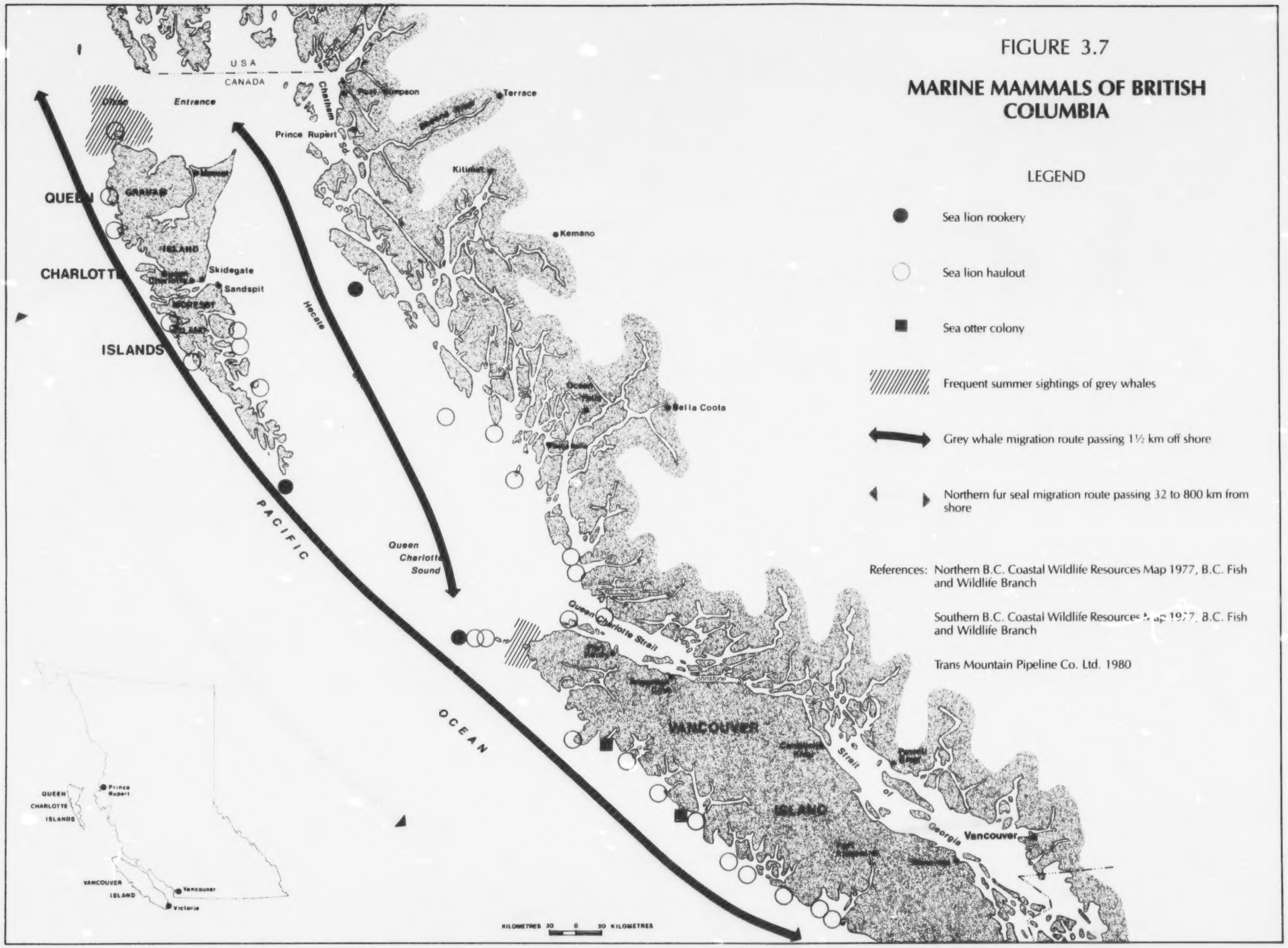

U.S.A.
CANADA
Dixon
Entrance
Masset
Graham
Island
Skidegate
Sandspit
Moresby
Island
QUEEN
CHARLOTTE
ISLANDS
Hecate
Chatham Sd.
Port Simpson
Prince Rupert
Terrace
Kitimat
Kemano
Ocean Falls
Bella Coola
PACIFIC
OCEAN
Queen
Charlotte
Sound
Queen Charlotte Strait
Johnstone
VANCOUVER
ISLAND
Strait
of
Georgia
Vancouver
KILOMETRES 20 0 20 KILOMETRES
QUEEN
CHARLOTTE
ISLANDS
Prince
Rupert
VANCOUVER
ISLAND
Vancouver
Victoria

FIGURE 3.7

**MARINE MAMMALS OF BRITISH COLUMBIA**

LEGEND

● Sea lion rookery

○ Sea lion haulout

■ Sea otter colony

▨ Frequent summer sightings of grey whales

⟷ Grey whale migration route passing 1½ km off shore

◀ ▶ Northern fur seal migration route passing 32 to 800 km from shore

References: Northern B.C. Coastal Wildlife Resources Map 1977, B.C. Fish and Wildlife Branch

Southern B.C. Coastal Wildlife Resources Map 1977, B.C. Fish and Wildlife Branch

Trans Mountain Pipeline Co. Ltd. 1980

## TABLE 3.7

## DISTRIBUTION AND ABUNDANCE OF MARINE MAMMALS POTENTIALLY AFFECTED BY OIL SPILLS IN BRITISH COLUMBIA

(after Bigg, 1977)

| Species | Distribution | Abundance |
|---|---|---|
| PINNIPEDS | | |
| Northern fur seal | B.C.; pelagic; migratory | several hundred thousand |
| Harbour seal | B.C.; littoral; residential | 35000 |
| N. elephant seal | B.C.; coastal; migratory | rare |
| Steller sea lion | B.C.; littoral; residential | 5000 |
| California sea lion | S. Van. Is.; littoral; migratory | 500-1000 |
| Sea otter | W. Van. Is.; littoral; residential | 100 |
| CETACEANS | | |
| Sperm whale | B.C.; pelagic; migratory | probably common |
| *Stenella* sp. | B.C.; pelagic; movements unknown | rare |
| Pacific common dolphin | B.C.; pelagic; movements unknown | rare |
| N. right-whale dolphin | B.C.; pelagic; movements unknown | rare |
| Pacific striped dolphin | B.C.; coastal-pelagic; movements unknown | probably common |
| Killer whale | B.C.; coastal-pelagic; residential | 300 |
| Risso's dolphin | B.C.; pelagic; movements unknown | rare |
| Pacific pilot whale | B.C.; pelagic; movements unknown | rare |
| Pacific harbour porpoise | B.C.; coastal; probably residential | common |
| Dall porpoise | B.C.; coastal-pelagic; residential | common |
| Baird's beaked whale | B.C.; pelagic; movements unknown | rare |
| *Mesoplodon* sp. | B.C.; pelagic; movements unknown | rare |
| Cuviers beaked whale | B.C.; pelagic; movements unknown | rare |
| Gray whale | B.C.; coastal; migratory | 11000 |
| Fin whale | B.C.; pelagic; migratory | probably common |
| Sei whale | B.C.; pelagic; migratory | probably common |
| Minke whale | B.C.; coastal; movements unknown | probably common |
| Blue whale | B.C.; pelagic; migratory | rare |
| Humpback whale | B.C.; coastal-pelagic; migratory | rare |
| Black right whale | B.C.; coastal-pelagic; migratory | rare |

ii) Pacific Striped Dolphin

The Pacific striped dolphin ranges from the Gulf of Alaska to Baja, California. From October to January schools may be sighted in Hecate Strait, the Strait of Georgia, the Strait of Juan de Fuca, and off the Queen Charlotte Islands. In general, their movements appear to be toward nearshore waters during the winter and toward offshore, open waters during the summer. Few of these dolphins are seen within 480 km of shore from June to August.

iii) Dall Porpoise

The Dall porpoise also moves offshore during the summer and nearshore during the winter. Schools have been seen most commonly in Hecate Strait, Queen Charlotte Sound, Dixon Entrance, Fitz Hugh Sound, and the Straits of Georgia and Juan de Fuca. Nearshore sitings are least frequent during the summer.

iv) Pacific Harbour Porpoise

This porpoise occurs year round in protected waters in British Columbia. According to Geraci and Smith 1977 (as cited in TMPL, 1980a), they are very susceptible to disturbance by humans and are not attracted to boats as other porpoises are.

v) Killer Whale

Killer whales are found throughout the year in the Straits of Georgia, and Juan de Fuca, Johnstone Strait, and as far north as Bella Bella. A number of distinct pods (groups) have been identified and their movements monitored. Their distribution extends into the Alaskan waters of the North Pacific. They feed on marine mammals, fish, squid and seabirds.

vi) Grey Whale

Grey whales travel within one or two miles of shore as they migrate between their winter breeding grounds in Baja, California and their summer feeding grounds in the Bering and Chukchi Seas. Some 40 individuals, however, remain to feed in Wickinninish Bay (Long Beach) over the summer. The migration route of Grey whales is illustrated in Figure 3.7. Grey whale sightings are frequent at Cape Scott where the whales concentrate before crossing Queen Charlotte Strait. Grey whales are termed bottom feeders. This means that they feed by sucking in bottom sediments and associated benthic organisms, straining out the organisms by forcing the sediments through baleen plates.

vii) Minke Whale

This small baleen whale travels solitarily or in small groups. It feeds by filtering water for krill and other plankton. As this animal has never been hunted, its current estimated population (19,000 individuals) is thought to be the maximum number that the north Pacific can support. This whale prefers protected inside waters and has been sighted frequently in Haro Strait. Because they are solitary and hard to follow, little is known of this whale's habits in British Columbia.

viii) Fin Whale

The Fin whale feeds on krill and is most commonly encountered in offshore, pelagic waters, or less commonly, in exposed straits surrounding Vancouver Island and the Queen Charlotte Islands. This large whale, averaging 20 m in length, has been heavily hunted with a resultant population decline from 44,000 to 17,000.

ix) Sei Whale

This baleen whale migrates between its wintering gounds in California, and the North Pacific, where its summer feeding grounds are located. It feeds by skimming the surface of the water for planktonic crustacea.

## 3.3 IMPACTS OF ROUTINE OFFSHORE HYDROCARBON OPERATIONS ON MARINE BIOLOGICAL RESOURCES

Impacts on marine biological resources are discussed in this section according to those which relate to all phases of hydrocarbon development (i.e., seismic, exploration, development, production) and to those which are related to a specific phase.

## 3.3.1 IMPACTS FROM DISTURBANCES COMMON TO ALL PHASES OF OFFSHORE PETROLEUM PRODUCTION

It should be kept in mind that impacts from these disturbances are greatest during the intense activity of the development phase.

### 3.3.1.1 Physical Presence of Offshore Platforms and Supply Vessels

Impacts of offshore rigs and their supply vessels relate to their physical presence and associated waterborne noise.

#### Physical Presence

The physical presence of a drill ship or drilling rig has not been shown to have adverse affects on fish or benthic invertebrates nor is the presence of fixed production platforms expected to have significant impacts. Indeed, oil production platforms attract large concentrations of fish (Mertens, 1976).

Marine birds are not expected to be significantly displaced from optimal feeding areas by the physical presence of ships or platforms, however, observations have been made of seabirds being killed by flying into lit platforms, or into ventilation system intakes (G. Kaiser and R. Brown, pers. comm., 1981, respectively). The extent of these problems is not known.

The presence of ships near sea lion rookeries and haulouts is known to cause mass evacuation of these areas as the animals seek the protection of the water. Geraci and St. Aubin (1980) speculate that such a disturbance may disrupt mother-pup pair bonds and may cause accidental pup mortality. Repeated disturbances may lead to colonial pinnipeds abandoning traditional breeding areas in favour of less suitable areas.

#### Associated Waterborne Noise

Waterborne noise from offshore hydrocarbon operations can originate from ships, drilling and production platforms, and aircraft and seismic signal devices (see Section 3.3.2). The low frequency noise normally associated with offshore petroleum operations is less harmfull than high frequency noise which has been shown to cause permanent ear damage to animals during laboratory studies (Norton Sound, 1981). The impact of noise on marine birds is mainly from aerial disturbances (see Section 3.3.1.2 following). The following discussion on the effects of waterborne noise on marine mammals comes mainly from Geraci and St. Aubin (1980).

A review of literature on the physiological effects of noise on mammals has shown that they appear to be "stress-mediated" and are possibly associated with lowered resistance to disease, increased vulnerability to environmental disturbances and result in endocrine imbalances which might in turn affect reproduction. It is conjectured that such stress-mediated effects might well apply to marine mammals as well. Marine mammal behaviour is dependent upon the highly sophisticated underwater communication system they possess. Any extraneous waterborne noise has the potential for interference with this communication. Information on these potential impacts is generally sparse, however, it has been observed that cetaceans readily habituate to low level background noise and seem to co-exist well with human activities associated with offshore hydrocarbon production. They will, however, react to and avoid certain types of sudden and variable noise. Loud underwater noise has been implicated in whale stranding and it is hypothesized that migration of minke whales and Baird's beaked whales off Japan has been disturbed by ship traffic. Concern over disturbance to traditional migration routes of bowhead whales in the Alaskan Beaufort Sea during the 1981 Eskimo hunting season prompted the institution of a temporary moratorium on seismic exploration (Oil and Gas Journal, Sept., 1981). Noise may also interfere with feeding activities and the use of established nursery areas. This lack of concrete evidence therefore suggests that caution should be exercised until knowledge of the effect of noise on marine mammals is complete.

#### 3.3.1.2 Air Traffic

Marine birds and marine mammals are the only groups expected to be affected by air traffic disturbance.

### i) Marine Birds

Cliff nesting marine birds such as the common murre, pelagic cormorants and nesting waterfowl are frightened from their nests by helicopter and airplane traffic. This subjects the eggs and the young to predation, exposure, and accidental displacement from the nest (Jones and Peterson, 1979 and Hunt, 1976; cited in Norton Sound, 1981). Preliminary studies indicate that repeated disturbance may reduce reproductive success and may cause the adults to abandon eggs and young (Gollop et al., 1972 and Scott, 1976; cited in Norton Sound, 1981). Air traffic routes should be chosen to avoid marine bird nesting areas. It is not known if aerial traffic will prevent marine birds from aggregating at preferred feeding and staging areas.

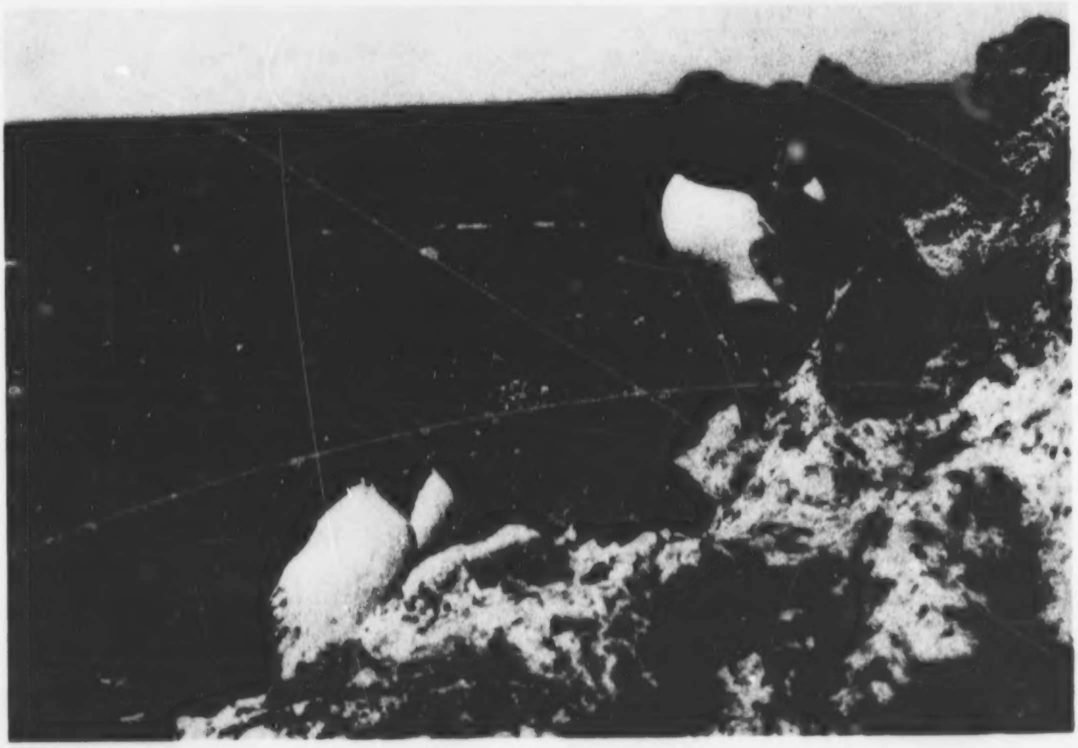


Plate 8: The British Columbia coastline is home to millions of breeding, migrating and resident marine birds. Repeated disturbance of cliff-nesting sea birds by aircraft will reduce reproductive success of the species (Common Murres).

*(British Columbia Provincial Museum photo)*

ii) Marine Mammals

Colonial pinnipeds such as Steller sea lions occupy traditional haul-outs and rookeries (breeding colonies). Disturbance of animals in these areas by air traffic may have adverse effects on the populations. For example, when approached by low flying aircraft many sea lions react by diving into the water. If disturbed by aircraft on a regular basis they may abandon these traditional areas in favour of less "suitable" sites which are not disturbed by air traffic (Geraci and St. Aubin, 1980).

Disruption of marine bird nesting sites and marine mammal haulouts and rookeries by noise from service aircraft is readily reduced by enforcing flight path and minimum altitude requirements.

### 3.3.1.3 Solid Waste Management

Deposition of solid wastes around a drill site alters the benthic habitat in that specific area. This undoubtedly results in the death of some benthic invertebrates and a change in the benthic community, but the magnitude of the impact will not be large (Mertens, 1976).

Concern regarding the deposition of solid waste on the ocean floor lies not so much with the effect it will have on marine resources but with the effect it will have on the fishing industry harvesting these resources. For example, since oil activities began in the North Sea trawl fishermen have complained about oil scrap on the fishing grounds, especially around abandoned wells. A recent study by the Norwegian Government bore out these complaints. Costs to North Sea trawl fishermen resulting from gear damage, lost catches and wasted time at sea is estimated to be in the millions of dollars. The Norwegian Government has attempted to remedy the situation by introducing a fishermen's compensation program, implementing tougher legislation for solid waste management, and by financing a program to clean up abandoned well head sites and fishing grounds.

A parallel situation can be avoided in British Columbia if legislation or regulations are used to manage waste discharge at sea. Replacement of a trawl net alone would cost a B.C. trawl fisherman $30,000. If the trawl doors were also lost the cost could rise to $50,000 (J. Richards, pers. comm., 1981). The overall cost to the fishing operation would be a great deal more.

#### 3.3.1.4 Sewage Treatment and Disposal

On the average, production platforms will produce 19 cubic metres of domestic and sanitary waste per day (McPhee, 1982). Discharge of raw sewage into the ocean introduces organic material which creates increased oxygen demand in the receiving waters and which results in the formation of sludge beds on the bottom. Deposition of sewage solids on the bottom can alter the habitat to an extent where molluscan shellfish, bottom fishes, and crustaceans may avoid the area.

In a review of waste disposal, Waldichuk (1968) classified the reference areas as coastal seaways. Because coastal seaways are very exposed to winds and tides which result in mixing and strong currents, they have the capability to dissipate or assimilate wastes. Sewage disposal in areas with reduced circulation or assimilative capacity will need to be evaluated on a site-specific basis.

#### 3.3.1.5 Minor Fuel Spills

Minor fuel spills are expected to occur frequently during the course of offshore petroleum exploration, development and production. The impact of small fuel spills on biological organisms may be lethal, depending on the type of fuel, volume, oceanographic conditions, etc. (see Section 3.3.5). When spills are of a localized nature and are small scale they are not likely to be of concern except in confined areas (e.g., estuaries) where habitat may become chronically contaminated. Under these circumstances minor fuel spills become a major concern. The adverse effects of chronic petroleum contamination on marine biological communities and organisms are well documented (Nelson-Smith, 1972a; Anderson and Malins, 1978). Chronic pollution is regarded as being more harmful than the effects of a single massive spill (Scarratt, 1981).

#### 3.3.1.6 Airborne Emissions

Airborne exhaust emissions from offshore vessels, rigs and aircraft used in relation to onshore facilities are not expected to be of concern.

### 3.3.2 IMPACTS DUE TO THE SEISMIC EXPLORATION PHASE

#### 3.3.2.1 Seismic Devices

Noise associated with modern seismic devices (e.g., sleeve exploder, electronic sparker, see Section 1.2) is harmless to fish but may be disruptive to marine mammals. Although marine mammals are not physically harmed the sound generated may disturb their normal behavioural and physiological functions. Burns *et al*. (1980; cited in Norton Sound, 1981) concluded that seismic exploration had the effect of decreasing the density of ringed seals on shore-fast ice in the Beaufort Sea.

### 3.3.3 IMPACTS DUE TO THE EXPLORATORY DRILLING PHASE

#### 3.3.3.1 Drilling Fluids and Drill Cuttings Disposal

Marine disposal of drilling fluids and drill cuttings are environmental concerns specific to the exploratory and development drilling phases. Drilling fluids are aqueous suspensions of clay in either an oil or water base. The major components (90%) of the fluid are barite, bentonite, lignosulphonate, and lignite. Other additives include biocides, rust inhibitors, deframers, etc. Drilling fluids serve many purposes (see Section 1.3) and their composition is varied accordingly. During the drilling of a 6100 m well, discharged drilling fluid alone may amount to 500 cubic metres (McPhee, 1982).

Information on the toxicity and environmental effects of drilling fluids was reviewed in a 1980 symposium entitled *Research on Environmental Fate and Effects of Drilling Fluids and Cuttings*. Impacts identified in this paper fell into two categories: those resulting from physical disturbances (i.e., sedimentation) and those which stemmed from the chemical make-up of the fluids and cuttings.

### i) Physical Impacts

During the drilling process, formation of a turbidity plume and sedimentation of bottom habitats are caused by the ocean disposal of drilling fluids and clean drill cuttings. The turbidity plume may decrease primary productivity and decrease the foraging efficiency of pelagic fishes. It is also known to clog the gills of fish (McPhee, 1982). While sedimentation of benthic inhabitants from suspended solids may interfere with their feeding behaviours and/or smother them (McPhee, 1982), Neff et al. (1981) report that most benthic infauna are relatively tolerant to this impact.

### ii) Chemical Impacts

Drilling fluids are known to be acutely toxic to some marine organisms (McLeary, 1975; cited in Neff et al., 1981). This may result from a single component or from the interaction of several components used to make the fluid. The acute toxicity of biocides has been demonstrated, and they are known to be persistent in the marine environment and therefore subject to bioaccumulation in the food chain. Metals of concern include chromium, lead, mercury, zinc, and copper. The persistence of these metals and their accumulation in marine sediments has been studied (MacDonald, in press). There is some potential for uptake and bioaccumulation. Histopathological damage from heavy metals has been observed in the Beaufort Sea (Harding, pers. comm., 1981).

The magnitude of these potential physical and chemical impacts will vary greatly, depending on the depth, currents, and density of effluent, etc. in a given location. A report prepared by Fenco (1979) summarized the situation as follows:

> "Drilling fluids discharged from a few exploration wells are not seen as a significant problem but, if numerous platforms are concentrated in a shallow area with promising reserves and also valued fish or shellfish stocks there may indeed be cause for concern."

In this regard, authorities regulating the Alaskan Beaufort Sea have identified sensitive biological communities where disposal of the drilling fluid and cuttings is not permitted. Disposal of drilling fluid and cuttings in British Columbia marine waters should be assessed on a site-specific basis and regulated accordingly.

### 3.3.4 IMPACTS DUE TO THE DEVELOPMENT PHASE

Once an economically viable petroleum reserve has been discovered the development phase can begin. Construction of facilities necessary for petroleum production takes place during this phase. Disturbances in the development phase are, for the most part, common to all phases of offshore petroleum operations. However, the level of activity (and hence degree of disturbance) from these common sources is highest during the development phase. These disturbances were discussed in Section 3.3.1. The major distinctive disturbance of the development phase that effects marine biological resources is the construction of submarine pipelines.

#### 3.3.4.1 Submarine Pipeline Construction

Submarine pipelines may be used in coastal British Columbia to transport hydrocarbon reserves from offshore production platforms to onshore facilities. At present, all of California's offshore production is piped ashore as is 97-98% of the Gulf of Mexico's production (Clark and Terrel, 1978). The use of subsea pipelines for hydrocarbon transport is a distinct possibility in British Columbia.

Environmental effects of pipelines are primarily related to their construction (Rooney-Char and Ayres, 1978). During the construction of a subsea pipeline a trench is jetted or blasted on the ocean floor. Benthic animals and plants in the path of the trench will be killed. Turbidity and siltation resulting from pipeline construction has been reported to affect benthic organisms more than 60 m (200 feet) from the pipeline construction site (Clark and Terrel, 1978). Environmental disturbances from nearshore pipeline corridors are of greater concern than offshore corridors. This is because nearshore pipeline corridors may traverse environmentally sensitive areas such as estuaries, marshes, dunes, and beaches. Pipeline siting plans should take into account environmental impacts associated with laying the pipeline. Mitigative measures should be planned and implemented to minimize environmental impacts. Pipeline landfall considerations are discussed in Chapter 4, Section 4.2.2.

The impact of trawl fishing gear on North Sea submarine pipelines was studied by Kiltau and Oude Hengel (1981). Their investigation showed that established design criteria and installation procedures for small and medium diameter pipelines protects them against the effects of trawl fishing gear crossover and anchor hooking. While trawl gear presents no hazards to properly designed and installed large diameter pipe, no cost-effective method will protect them from anchor hooking.

## 3.3.5 IMPACTS DUE TO THE PRODUCTION PHASE

### 3.3.5.1 Tanker Traffic

Tankers may transport petroleum to onshore terminals. The effect of the physical presence of ships on marine organisms was discussed in section 3.3.1.1

### 3.3.5.2 Ballast and Bilge Water Discharge

Petroleum storage tanks on tankers may be filled with seawater to provide stability. This ballast water is discharged at an offshore or onshore oil loading terminal. The current practice is to require all ballast water to be discharged to tanks for treatment. However, this is less easily accommodated at offshore platforms. The U.S. Dept. of Transportation 1975 (cited in Clark and Terrell, 1978) stated that "more than seventy percent of all oil discharged or spilled from tankers occurs during routine operations, particularly bilge washing". This represents a considerable input of hydrocarbons to the marine environment. This may have significant impacts on marine biota depending on the characteristics of the receiving waters. The trend towards separate ballast tanks in large tankers and the use of Load on Top (L.O.T.) systems reduces the amount of oily ballast water discharge. This procedure is still seen as a serious problem and strict regulation is required.

### 3.3.5.3 Discharge of Formation Waters

Formation waters are very saline, high mineral content waters which often have hydrocarbon contamination. They are produced throughout the production phase. Formation waters may be reinjected into the formation or discharged to sea. If ocean discharge is chosen then the water is separated from oil contamination. Standards limiting the amount of hydrocarbons in formation water discharges have been established in the United States at 50 ppm maximum. Similar standards should be developed for Canada. Discharged formation waters are void of oxygen and high in mineral content and according to Baker (1978; cited in Fenco, 1979) could be of considerable environmental concern if discharged onto sensitive nearshore habitats. Potential for adverse biological impacts should be evaluated on a site-specific basis.

## 3.3.6 IMPACTS OF MAJOR OIL SPILLS ON MARINE BIOLOGICAL RESOURCES

Non-routine events associated with offshore petroleum exploration include gas blow-outs, liquefied natural gas (LNG) fires, oil blow-outs, pipeline ruptures, storage tank ruptures, and tanker spills.

Liquefied natural gas (LNG) does not constitute a pollution threat as it is only slightly soluble in water and evaporates readily. For these reasons its impact on marine biological resources is expected to be insignificant. Therefore, the focus of this section will be on the impact of major oil spills on marine biological resources.

Approximately six million tons of oil enter the world's oceans yearly (see Table 3.8). Although accidental oil spills account for only 6% of this figure, the spectacular nature of spills has attracted much attention. The documented biological and ecological impacts of major oil spill events

### TABLE 3.8

### SOURCES OF PETROLEUM IN THE MARINE ENVIRONMENT[a]

| | Natural | Intentional | Accidental |
|---|---|---|---|
| Natural seeps | 10% | | |
| Offshore Production | | | 1% |
| Transportation | | | |
| LOT tankers | | 5% | |
| non-LOT tankers | | 13% | |
| Dry docking | | 4% | |
| Terminal operations | | | |
| Bilge bunkering | | 8% | |
| Tanker accidents | | | 3% |
| Non-tanker accidents | | | 2% |
| Coastal Refineries | | 3% | |
| Atmosphere | | 10% | |
| Coastal Municipal Wastes | | 5% | |
| Coastal (nonrefining industrial wastes) | | 5% | |
| Urban Runoff | | 5% | |
| River Runoff | | 26% | |
| Total | 10% | 84% | 6% |

[a] Recalculated from National Academy of Sciences.

Source: Hyland and Schneider, 1976

ranges from negligible to catastrophic (Vandermeulen, 1981). This variability in oil spill impacts is a result of the interplay and relative contribution of the following as identified by Sanborn (1977):

- type of petroleum
- volume spilled
- method of clean-up
- oceanographic conditions
- meteorological conditions
- biota of the area

- season
- previous exposure of the area to oil
- exposure to other pollutants

When considering the complexity of the interrelationships of the above nine factors it is easy to understand the difficulty in predicting ecosystem effects from a spill or in trying to compare the impacts from two different spills.

The impacts of an oil spill are experienced at all trophic levels of an ecosystem and while the impact at any one level can be directly or indirectly related to other trophic levels each level may also show physiological changes unique to its own metabolic system.

Plate 9: The impact of spilled oil on near-shore communities will depend on many factors including the type of oil, biota of the area, degree of weathering and physical exposure (Mussels and kelp, *Mytilus sp. and Macrocystis*).

*(Ministry of Environment photo)*

Delineation of specific oil spill effects at various ecosystem levels has been undertaken by a host of researchers. In general, effects on biological organisms can be attributed to the physical and chemical properties of oil. Lighter oils, with a higher proportion of aromatic hydrocarbons, evaporate quickly and are chemically more toxic than heavy fuel oils and some crude oils which persist longer in the environment and may cause damage due to their physical properties (e.g., smothering).

Many summary lists categorizing specific oil spill effects have been published (Thompson, 1977; Scarratt, 1981; Percy, 1981). The discussion of impacts on biological groups undertaken in this review incorporates and expands upon the description of five specific effects outlined by Moore (1973; cited in Hyland and Schneider, 1976):

i) Direct lethal toxicity is a function of the chemical properties of oil. Death results from interference with cellular, subcellular and physiological processes (e.g., disruption of membrane activities). Effects on the population are site specific and recovery is dependent on recruitment from unaffected areas.

ii) Sublethal effects result from both the chemical and physical properties of oil and are potentially the most devastating of the five effects of oil on marine organisms. Sublethal effects cause subtle changes in the behaviour and/or physiology of the organisms such that individual's and/or population's survival is potentially affected (e.g., alteration of chemoreception or change in metabolism).

iii) Effects of direct coating result from the physical and chemical properties of oil and include smothering, loss of insulative properties, dislodgement from the substrate due to the additional weight of the oil, and entanglement of appendages or filtering organs. The effects are immediate and site-specific. Recovery is dependent on oil persistence in the habitat.

iv) Incorporation of hydrocarbons into biological organisms may result from ingestion or absorbtion across gill membranes or possibly inhalation. This gives rise to two major concerns: (i) tainting, and (ii) incorporation of polycyclic aromatic hydrocarbons (PAH) which are potentially carcinogenic. These concerns stem mainly from the residual or heavier components of petroleum because of their persistence in the environment. Bioaccumulation and biomagnification of petroleum hydrocarbons and their breakdown products in the food web are major concerns, especially for commercially harvested species (i.e., fish and invertebrates).

v) Changes in biological habitats result from the physical properties of oil. Persistence of oil on or in the substrate will determine the overall effect on the community as contamination may effect the integrity of the sediment for benthos or the suitability of the substrate as a surface for settling larvae and spores.

Keeping in mind the impacts outlined above, the following sections describe briefly the potential impacts of a major oil spill on marine biological resources. It should be remembered that this preliminary environmental assessment relies greatly on laboratory studies. The application of these studies to the field situation is conjectural at this point.

#### 3.3.6.1 Marine Bacteria

When hydrocarbons enter the marine environment there is major shift in the structure of microbial populations as the growth of hydrocarbon utilizing bacteria is stimulated (Colwell *et al.*, 1978). This author notes that "the significance of such a shift can only be inferred until further studies are completed. Clearly, however, changes in the populations of [certain] physiological groups of micro-organisms will affect the total microbial ecology of an oil-impacted system." Biodegradation of spilled oil is covered in Section 5.8.2.5.

#### 3.3.6.2 Phytoplankton

A number of experiments have been conducted to determine the impact of hydrocarbon pollution on phytoplankton communities. Many of the studies have been summarized by Snow (1981). In general, when hydrocarbon levels are low, phytoplankton growth is enhanced and when hydrocarbon levels are high, growth is depressed. There are species specific variations in tolerance levels which would lead to a shift in species composition in the event of a spill.

A controlled ecosystem experiment conducted by Lee et al. (1977; cited in Snow, 1981), showed that when subjected to the water soluble fraction of No. 2 fuel oil, phytoplankton community composition shifted from diatoms to microflagellates. Young fish are the favoured primary carnivore in a diatom community. Ctenophores (a type of jellyfish) are favoured in a microflagellate dominated community. These energy pathways are depicted below. (TMPL, 1980a).

a) Nanophytoplankton (e.g., small flagellates) ---> small zooplankton ---> ctenophores.
b) Microphytoplankton (e.g., large diatoms) ---> large zooplankton ---> young fish.

An oil spill which causes a shift in phytoplankton community structure therefore appears to have the potential of affecting higher trophic levels, including commercial fisheries, particularly if phytoplankton are affected during sensitive life stages of marine fish.

Snow (1981) maintains, however, that "acute affects are not ordinarily expected to persist or to drastically alter the overall abundance of phytoplankton in a given open ocean area." Scarratt (1981) adds that the "impact of supression of primary production upon subsequent fish stock biomass will be undetectably small or negligible." The impact on phytoplankton communities from a spill event at sea is expected to be minor and of short duration especially in light of the fact that the toxic components of oil are lost after a few days and that the reproductive and inoculation rates of phytoplankton tend to mitigate the impact. In support of these comments Smith (1968), reports that during the wreck of the Torrey Canyon (March, 1967), phytoplankton populations were of the type normally found in the English

Channel during early spring and that diatoms and dinoflagellates were healthy. Only the surface-floating Prasinophyceae were apparently vulnerable to the toxic components in oil.

Chronic hydrocarbon contamination may have more severe long-term effects on phytoplankton community structure than a single open ocean spill of oil. Sources of chronic oil contamination might originate from a long-term oil blow out, routine operations of facilities or the gradual release of sediment-bound oil.

In conclusion, an open ocean petroleum spill would probably have no lasting impact on marine phytoplankton communities. Effects on higher trophic levels dependent on phytoplankton production would likely be undetectable. Chronic petroleum contamination may have more severe effects than a major spill.

### 3.3.6.3 Zooplankton

A majority of the studies (80-90%) investigating the effects of oil on zooplankton have been conducted in the laboratory. Most of these involved single species. A limited number of field studies have been summarized by Wells (in press). These are discussed below:

Laboratory studies measuring direct lethal toxicity, behavioural aberrations, changes in feeding rates, growth, development, physiology and reproduction, as well as uptake and depuration of oil have been conducted. Collectively, these studies show that naturally dispersed oil is acutely toxic to various groups of zooplankton. There are many important groups that have yet to be fully studied.

Besides lethal toxicity other responses by zooplankton have included paralysis, depressed feeding rates, reduced success in fertilization, decreased survival, and abnormal development in larval forms.

The limited field observations of zooplankton which have been made indicate that individual organisms at spills have been affected through direct toxicity effects, direct coating of oil, sublethal effects, and by uptake and retention. Interestingly, copepods (a group of marine crustaceans) ingest and defecate oil particles without apparent ill effects. Spill sites observations are required to determine whether impact data derived in the laboratory reflects what occurs in the field. In general, little damage or significant prolonged change to zooplankton populations is detected in open ocean areas near a spill and it is unlikely that a correlation could be made between the two because of large, natural variabilities in zooplankton biomass (LeBrasseur, pers. comm., 1981). Large spills in coastal sounds, inlets, and bays could contaminate the water column for many weeks during the crucial spring and summer peaks of productivity. Wells (in press) states that "in such cases, the susceptibility of local populations of zooplankton to significant lethal and sublethal damage would probably be high, and might rank closely with the known level of immediate effects imparted by oil spills to birds and intertidal organisms." Recovery would likely be fairly rapid due to recruitment of individuals from other areas.

### 3.3.6.4 Marine Plants

The impact of oil on intertidal marine plants is due mainly to direct coating by oil; the increased plant weight causing them to be easily dislodged from the substrate by wave action. This was the cause of an extensive loss of intertidal Fucus following the Amoco Cadiz spill. Significant losses of intertidal algae have been noted following a number of other spills including the Tampico spill off Baha, Mexico and the Arrow spill in Chedabucto Bay, Nova Scotia. Intertidal species such as the commercially valuable red alga Porphyra and Iridaea are especially vulnerable to oil contamination. This is presumably due to the fact that they do not have the muco-polysaccharide coating which species such as kelp secrete and which seems to prevent oil from adhering. For example, Macrocystis beds in the Santa Barbara Channel blowout were not appreciably damaged by oil. Subtidal marine algae do not suffer severe or noticeable mortality from oil spills unless smothered or exposed to highly toxic fractions.

Recovery of oil contaminated shorelines may be delayed until the oil has been removed and normal successional patterns of recolonization are allowed to proceed (Southward and Southward, 1978). Estuarine ecosystems are very vulnerable to oil pollution because they are characteristically sheltered, low-energy environments where little self-cleaning by wave action can occur. Thomas (1981) states that the most important factor in determining the magnitude and impact of an oil spill in both the long and short term is the persistence of oil retained in the habitat. Contamination of low energy estuarine ecosystems will therefore have significant impacts on the biota.

Oil which becomes entrained in the sediments can become a source of chronic contamination for the area. Oil penetrating the sediments can effect salt marsh plants by destroying the root system or inhibiting germination. Foliage may be killed by direct oil contact. Oil in the sediments may also inhibit oxygen diffusion into the substrate. This sublethal effect may reduce the productivity of the area. Loss of salt marsh vegetation will reduce sediment stability in the estuary. Extensive mortality of salt marsh plants was noted after the diesel oil spill from the "Tampico Maru" (North, 1961; cited in Nelson-Smith, 1968). Destruction of salt marsh communities from chronic oil pollution has been documented by Nelson-Smith (1972).

High mortality of seagrasses (eelgrass) due to oil spills has been documented. For example, during the Santa Barbara Channel blowout (Foster _et al_., 1971; cited in TMPL, 1980) recorded up to 100% mortality at some monitoring stations. Following an oil spill in Puerto Rico, _Thallasia_, a warm water eelgrass, suffered extensive mortality.

Eelgrass and salt marsh vegetation are major components of the primary production level in the estuarine food chain. Destruction of these communities through the effects of an oil spill reduces the energy flow within the the estuary ecosystem and has a serious impact at higher trophic levels (Sanborn, 1977). Baker (unpub.) maintains that elimination of saltwater wetland vegetation alone will reduce the carrying capacity of estuarine ecosystems by approximately 50% in a typical case.

Due to the rarity of estuaries and their known importance to fish and other marine life, these systems must be afforded maximum protection in pre-planning for offshore oil production.

### 3.3.6.5 Marine Invertebrates

The impact of oil on marine invertebrates has been documented both in the field and in the laboratory. The impacts may be broken down into those attributable to either the physical or the chemical properties of oil and are discussed according to the impact categories outlined in the introduction to this section (i.e., direct lethal toxicity, sublethal effects, direct coating effects, incorporation effects, and habitat alteration). Most of the field research on the impacts of oil has been on species occupying intertidal and nearshore shallow subtidal habitats; information on deeper subtidal communities is becoming more abundant.

#### i) Direct Lethal Toxicity

Many short term lethal toxicity tests have been carried out on benthic species using different types and fractions of crude oil. These studies have unambiguously demonstrated the toxicity of petroleum fractions to an array of marine invertebrates. The available data have been concisely tabulated for taxonomic groups in Craddock (1977). Concentrations of oil in seawater which are lethal to adult stages of marine organisms range from 1-100 ppm. For the most sensitive larval and juvenile forms, lethal effects may occur betwen 0.1 and 1.0 ppm (Hyland and Schneider, 1976).

Direct toxicity effects are most pronounced in the low intertidal and nearshore shallow intertidal communities. Field studies have shown varying degrees of mortality among marine invertebrates. Near total destruction of the fauna and flora of the Brittany coast was recorded from the Amoco Cadiz spill (Vandermeulen, 1981).

Rice *et al*. (1976) found that benthic invertebrates fell into two general categories: sensitive and resistant. The sensitive species were subtidal benthic inhabitants and the resistant species were intertidal fauna. They postulated that intertidal species were more resistant to petroleum contamination because of the variety of adaptions employed to cope with their naturally stressful intertidal environment. Deeper subtidal communities may also be affected by petroleum toxicity. Until 1978 it was commonly thought that oil concentrations under a spill area would be high only in the upper 5-10 m of the water column, dropping off rapidly to provide a protective buffer zone for subtidal bottom fauna. However, while studying the Amoco Cadiz spill, Marchand (1978; cited in Vandermeulen, 1981) observed lethally high concentrations of oil uniformly throughout the water column under certain conditions and unexpected high mortalities of benthic fauna such as sea urchins, shellfish, and amphipods. It is therefore apparent that the lethal toxicity of spilled oil may affect marine benthic fauna in a wide range of habitats, given the right conditions.

Particularly vulnerable to direct toxicity from spilled oil are marine invertebrate eggs and larvae because they are 1) highly sensitive to petroleum and 2) planktonic in the upper layers of the water column. There are, however, no reports that spilled oil has ever affected recruitments to any shellfish stock (FAO, 1977). This is probably due to the large amount of natural variability in recruitment which precludes detection of population declines due to oil spills.

ii) Sublethal Effects

Many sublethal effects of petroleum hydrocarbons on benthic invertebrates have been identified from laboratory experiments. Marine organisms respond to sublethal effects in the ppb range (10-100 ppb); some commercially or economically important species (e.g., certain shellfish) respond between 1 and 10 ppb. Hyland and Schneider (1976) have tabulated much of the available data. Because laboratory conditions are inherently stressful to marine organisms there is a danger in extrapolating results to the field situation. Evidence to date strongly suggests that sublethal effects of petroleum on marine organisms are potentially disruptive. Observed effects on various physiological processes have been discussed according to taxonomic group by Johnson (1977) who emphasizes the importance of sublethal

Plate 10: Commercial clam beds may be highly impacted by an oil spill because of chronic re-oiling due to the persistence of oil in the sediment.

(Ministry of Environment photo)

effects when he states that: "a response induced in a marine organism under laboratory conditions may, in effect, be a lethal response in the marine environment if an animal's ability to avoid predators or cope with physiological stress is impaired."

A discussion of sublethal effects is also undertaken by Percy (1981) who categorizes responses according to their ecological consequences. These categories are as follows:

a) Subcritical effects - effects of direct consequence only to the individual organism
b) Critical effects - effects which are likely to have direct ecologically significant consequences

The reader is referred to either Johnson (1977) or Percy (1981) for a more complete, fully referenced discussion of the sublethal effects of petroleum hydrocarbons on marine invertebrates. The following short discussion simply overviews the potential sublethal effects in the framework established by Percy (1981).

a) Subcritical effects include changes in physiological processes. For example, petroleum products have been shown to both stimulate and depress the metabolic rate of benthic invertebrates depending on the species and concentration of hydrocarbons. Neuromuscular effects have been noted and may take the form of reduced muscular activity or, in contrast, hyperactivity, or they may reflect alteration in structure and functions of cellular membranes. Regulation of ionic and osmotic balance of body fluids is dependent upon the integrity of biological membranes as is chemoreception. Both functions are affected by hydrocarbons. If hydrocarbon stress was sufficiently great or prolonged then "critical" effects would be manifested from these "subcritical" effects. For example, a continued decrease in neuromuscular (locomotory) activity would have serious ecological consequences for species in which the pursuit of prey or escape from predators are vital functions.

b) Critical effects include changes in behavioral and physiological processes. Behavioural disturbances may have their origins in impaired chemoreception ability (discussed above) and may result in a decrease in reproductive capability and/or, in the case of crustaceans, interference with the ability to detect and respond to food.

Critical physiological effects include a decline in growth rates, interference with reproductive processes, impairment of larval growth and development and interference with molting in crustaceans. Percy (1981) states that growth may prove a useful indicator of pollution stress in benthic organisms and that "disturbance of this process would seem to entail clear ecological consequences and probably reflects the cumulative impact of interacting physiological, biochemical or behavioral disfunctions." The degree to which growth is impaired by petroleum varies among species.

Growth and the molt cycle are closely associated processes in crustaceans. Several studies have shown that benthic crustaceans are more sensitive to petroleum during molting than during the intermolt period. This could have serious consequences for species such as dungeness crabs that migrate into shallow coastal waters to migrate and reproduce. Conversely, other studies have shown that some species appear largely unaffected or even slightly stimulated by petroleum exposure during the molting process.

Petroleum hydrocarbons have been shown to affect most of the distinct phases of reproduction of several benthic organisms, the most sensitive phase varying with the species. Interference with reproductive processes of a species may clearly result in changes in population structure and community dynamics.

Information available clearly indicates the range of potential sublethal effects on marine organisms. However, coherent patterns are lacking and the relevance of these laboratory studies to natural conditions remains to be established.

### iii) Direct Coating

The physical impacts from direct oil coating are most pronounced along exposed shorelines populated by attached or relatively immobile species such as barnacles, mussels, snails, and limpets (Hyland and Schneider, 1976). Impacts occur mainly in the intertidal area, particularly the upper intertidal, where oil may become stranded and persist for long periods of time (TMPL, 1980). Physical effects on the organism include smothering, cementing to the substrate, and dislodgement from the substrate due to the additional weight of an oil coating. Many species are relatively resistant to oil because of their adaptive strategies. For example, some species produce copious quantities of mucous which prevents oil from adhering to them while other species (e.g., bivalves) are able to isolate themselves from their environment for short periods and may thereby survive temporary heavy oiling (Percy, 1981).

### iv) Incorporation of Petroleum Hydrocarbons

For a complete discussion of accumulation, metabolism, and biotransformation of petroleum hydrocarbons in marine invertebrates the reader is referred to Varanasi and Malins (1977).

Incorporation of petroleum hydrocarbons into marine invertebrates may occur in three ways: 1) ingestion with food, 2) absorbtion from seawater, and 3) absorbtion from oiled sediments. The rate of accumulation in marine organisms varies, however most marine organisms are able to accumulate substantial amounts directly from seawater. For example, bioaccumulation of 200-300 times over the levels in the water occur in crustacea (Varanasi and Malins, 1977).

The effects of bioaccumulated hydrocarbons on marine organisms requires further investigation. Effects may range from altered behaviour to changes in physiology, or the effects may affect species survival in more subtle ways. Blackman and Mackie (1974; cited in Varanasi and Malins, 1977) for example, concluded that oil contaminated shrimp were eaten more frequently by plaice (Pleuronectes platessa) than clean shrimp, presumably because they were easier to catch.

The consequences of petroleum accumulation in biological organisms raises other concerns (i.e., tainting and potential carcinogenicity), especially for commercial species. A brief discussion of these concerns follows.

a) Tainting--Shellfish may become tainted in water containing as little as 1 ppb of hydrocarbons (Hyland and Schneider, 1976). This will negate their utilization as human food. Molluscan shellfish are especially vulnerable to tainting because they occupy sediment beach habitats which have high oil retention capabilities causing chronic re-oiling and contamination.

b) Potential carcinogenic (cancer causing) effects--Petroleum hydrocarbons contain components (polycyclic aromatic hydrocarbons, PAH) which have been implicated as potentially carcinogenic (Varanasi and Malins, 1977). There is evidence that these compounds are responsible for inducing neoplastic growth and lesions in a variety of marine benthic organisms. These growths could have severe impacts on individuals and populations if gill and reproductive tissues were involved (Percy, 1981).

Depuration rates for biological organisms vary on the basis of the activity of their enzymes (aryl hydrocarbon hydroxylases, AHH). Crustaceans have relatively high levels of AHH activity and metabolize petroleum fairly rapidly (Anderson and Malins, 1978). Conversely, there is some doubt that molluscs (e.g., the softshell clam Mya arenaria, the edible mussel Mytilus edulis, and the oyster Ostrea edulis) can metabolize petroleum hydrocarbons at all (Vandermeulen and Penrose, 1978).

Predators of these species are therefore subject to accumulation of oil from ingestion of contaminated tissues. Pathways of bioaccumulation and biomagnification in the food chain are discussed in Varanasi and Malins (1977) who conclude that further investigations are required to elucidate the importance of bioaccumulation in higher level predators.

### v) Habitat Alteration

The impact which sunken oil has on benthic communities is not fully known. Through the processes of physical or chemical dispersion, adherence to silt, and sinking it is estimated that up to 10% of spilled oil may end up on the bottom, giving rise to concentrations in the sediments in the range of 10-100 ppm (Scarratt, 1981). Oil trapped in the sediments will act as a reservoir, slowly releasing hydrocarbons to the environment for many years (Gilfillan and Vandermeulen, 1978). This type of chronic pollution is reported to have a greater impact on biological communities than is a single massive spill (Thomas, 1981). Behavioural effects involving repulsion from oil tainted sediments and substrates has been reported (Percy, 1981), and delay in settling is a major factor in the mortality of larval invertebrates. Also, actual incorporation of oil into the sediments will alter the integrity of the substrate which may impact benthic inhabitants (Sanborn, 1977).

#### 3.3.6.6 Fish

Laboratory bioassays have proven the lethal toxicity of petroleum hydrocarbons to fish (Hyland and Schneider, 1976). However, there are only a few records of significant fish kills resulting from spilled oil (Penrose, 1981). This may be due to the fact that contaminated fish may leave the area before sampling occurs and/or the oiled fish which die, may sink. Scarratt (1981) states that it is unlikely that adult or commercial sized fish would be killed because concentrations of oil in the direct vicinity of a slick are low. Almost all fish kills which have been recorded have occurred when oil has contaminated relatively sheltered and shallow waters or when fish held in mariculture pens were unable to avoid contamination (TMPL, 1980a).

Until recently, there was no evidence in the literature that floating oil affected the recruitment to any fish stock (FAO, 1977). However, Vandermeulen (1981) referred to the loss of a complete year class of groundfish (plaice) resulting from the Amoco Cadiz spill off the coast of Brittany in 1978. This population recovered within 2 years via recruitment from unaffected stocks (Vandermeulen, pers. comm., 1981). The potential for significant impacts on British Columbia fish stocks may therefore exist. However, an accurate assessment of the impact of petroleum on fish will be difficult because 1) the effects of petroleum on British Columbia fish species are largely unknown and 2) the life history and ecology of many important fish species in this study area are poorly understood.

The following discussion describes the potential impacts of petroleum spills on commercial fish species in British Columbia (i.e., Pacific salmon, Pacific herring, halibut, and groundfish). While no attempt has been made to document the impacts on non-commercial species the types of impacts may be the same. The discussion is structured according to the five categories of effects outlined by Moore (1973; cited in Hyland and Schneider, 1976) and described briefly in the introduction to this chapter.

### 1) Direct Lethal Toxicity

The migratory and/or mobile behaviour of most adult fishes makes them less vulnerable to the direct effects of oil pollution than the egg, larval, and juvenile stages. Species which are most vulnerable are those which have the greatest probability of coming in contact with, or in close proximity to, an oil spill at some stage of their life history. Table 3.9 lists the major commercial species caught in British Columbia and details the life history stages regarded as having the greatest vulnerability to direct lethal toxicity.

The toxicity of petroleum hydrocarbons to Atlantic herring (*Clupea harengus harengus*) has been demonstrated (Kuhnhold, 1972). The relative vulnerability of Pacific herring (*Clupea harengus pallasi*) to an oil spill has been ranked greater than that for groundfish and other non-salmonid fishes (McCallister and Sherwood, 1978). This high rating is due to the vulnerability of their eggs and larvae. During February and March, herring migrate into bays and inlets along the British Columbia coastline where they deposit their eggs on rocks, kelp and other algae, and seagrasses in the intertidal and shallow subtidal regions. The incubation period for the eggs is 2-3 weeks, after which there is a 3-4 month larval period spent in coastal surface waters. Juvenile herring move gradually offshore as they grow (Hourston and Haegele, 1980). If herring eggs were covered by oil, mortality due to direct toxicity and asphyxiation would likely be 100% (Waldichuck, 1978).

Because Pacific salmon (Oncorhynchus spp.) are highly mobile and migratory and inhabit the open ocean for most of their life, their susceptibility to direct toxicity from an oil spill would be limited to those times when they are less mobile and/or concentrated in a small area (i.e., during their first year in the ocean and in their final year when they return to spawn). There are, however, no reported instances of salmon kills in the literature. After migrating downstream to the sea in the spring, juvenile salmon spend a varying period of time in estuaries and littoral nursery areas. Their high concentrations in these shallow waters makes them particularly vulnerable and their sensitivity to petroleum has been documented (Rice, 1973; Morrow, 1973). The additional stresses of entering seawater increases (doubles) the sensitivity of juvenile salmon to petroleum (Moles et al., 1979).

There is some evidence that juvenile salmon may avoid oil contaminated areas (Rice, 1973; Sprague et al., 1981). If avoidance is related to the swimming ability of salmon, then coho and sockeye juveniles would be least affected because they are larger and therefore stronger when they migrate to sea. As they grow, juvenile salmon become less habitat dependent and disperse into deeper coastal waters, moving generally northward as they begin their ocean migration (Neave, 1964; Godfrey et al., 1977; French et al., 1976; Neave and Bakkala, 1976). Direct toxicity would therefore be of less concern due to the rapid dilution of toxic oil concentrations in open waters (Penrose, 1981). (Note: Some Georgia Strait salmon stocks move southward through Juan de Fuca Strait before beginning their northward migration to the Gulf of Alaska). Mature adult salmon returning to spawn concentrate in estuaries until river conditions are acceptable. Oil contamination in an estuary at this time could be extremely damaging. The toxic effects of hydrocarbons to salmon have been reviewed by Gordon et al. (1977).

The life histories of 13 commercially valuable Pacific coast groundfish species have been reviewed with respect to their potential vulnerability to the direct effects of a major oil spill (see Table 3.9). A generalized groundfish life cycle is described below.

Spawning takes place during the winter, usually between November and March. Eggs may be benthic, demersal, pelagic/planktonic, or floating. Incubation may last for up to four weeks depending on the species and water temperature. (Note: Pacific ocean perch (Sebastes alutus) and other rockfishes of the genus Sebastes are ovoviviparous i.e., young are born as yolk-sac larvae (Hart, 1973)). Rockfishes of the genus Sebastolosus deposit pelagic, jelly-like masses in which the eggs incubate. Larvae take up to four months for complete metamorphosis into adult form. After metamorphosis is complete juveniles settle to the bottom. Environmental conditions during the egg and larval stages influence the survival rate and distribution of the species. Maturation time varies among species and between sexes of the same species and may take as long as 12 years (e.g., male Pacific halibut).

Direct lethal toxicity from a major spill would be unlikely for adult groundfish, which occur mainly in deep waters (i.e., >40 m). Juveniles (e.g., sablefish) may occur in shallow water for short periods thereby increasing their vulnerability. Species regarded as having the greatest potential vulnerability to direct toxicity effects are: English sole (because of their floating eggs and larvae), starry flounder (because of their floating eggs), and lingcod (because they deposit benthic egg masses in shallow water).

The toxic effects of petroleum on Pacific coast groundfish have not been investigated in the laboratory or in the field; however, lethal effects of oil on bottomfish species elsewhere in the world have been documented. Kuhnhold (1972) carried out laboratory experiments on the effects of various crude oils on cod eggs and larvae (Gadus morhua) and the larvae of Atlantic herring (Clupea harengus) and plaice (Pleuronectes platessa), all of which are of commercial importance. He found that both eggs and larvae are sensitive to oil and that young larvae are much less resistant than embryos.

## TABLE 3.9

## SENSITIVE LIFE STAGES OF MAJOR COMMERCIAL FISH SPECIES

| SPECIES | LIFE HISTORY STAGE(S) WITH GREATEST VULNERABILITY (FROM HART, 1973) | SPECIES | LIFE HISTORY STAGE(S) WITH GREATEST VULNERABILITY (FROM HART, 1973) |
|---|---|---|---|
| English (Lemon) Sole<br>Parophrys vetulus | Pelagic eggs and larvae | Pacific Halibut<br>Hippoglossus stenolepis | Eggs float at depth offshore<br>Juveniles inhabit shallow water |
| Starry Flounder<br>Platichthys stellatus | Pelagic eggs and larvae<br>Shallow water spawners | Sablefish (blackcod)<br>Anoplopoma fimbria | Pelagic eggs float at depth offshore<br>Juveniles found inshore |
| Lingcod<br>Ophiodon elongatus | Benthic egg masses spawned in shallow water or sometimes intertidally<br>Larvae and juveniles shallow water | Pacific Ocean Perch<br>Sebastes alutus | Young born alive at depth offshore<br>Pelagic juveniles |
| Rock Sole<br>Lepidopsetta bilineata | Demersal adhesive eggs inshore<br>Larvae occur in shallow water | Pacific Cod<br>Gadus macrocephalus | Demersal, adhesive eggs<br>Benthic larvae |
| Petrale Sole (Brill)<br>Eopsetta jordani | Eggs float at depth offshore<br>Larvae never found off Canada | Pacific Hake<br>Merluccius productus | Pelagic eggs and larvae offshore |
| Dover Sole<br>Microstomus pacificus | Eggs float at depth offshore<br>Prolonged pelagic larval life | Pacific Salmon<br>Oncorhynchus spp. | Emigrating juveniles<br>Estuarine adult concentrations |
| Arrowtooth Flounder (Turbot)<br>Atheresthes stomias | Eggs found between 200 m and the surface offshore | Pacific Herring<br>Clupea harengus pallasi | Adhesive demersal eggs spawned in shallow nearshore or intertidal water; planktonic larvae |
| Butter Sole<br>Isopsetta isolepis | Eggs demersal, adhesive in Skidegate Inlet | | |

Resistance increased with advancing resorbtion of the yolk sac. Mironov (1972) also documented the sensitivity of fish eggs and larvae to oil. Rice et al. (1975) described the order of increasing sensitivity to oil as eggs, adult fish, larvae.

Because laboratory data cannot be safely extrapolated to a field situation an accurate prediction of the potential impacts of direct lethal toxicity of petroleum hydrocarbons to fish is difficult to make.

### ii) Sublethal Effects

Unlike the limited occurrence of lethally toxic concentrations of oil in seawater following spills, hydrocarbon concentrations required to elicit sublethal effects in biological organisms have been demonstrated more frequently. Sublethal responses in marine organisms have been summarized by Hyland and Schneider (1976) and generally occur in the 10-100 ppb range. Patten (1977) categorizes sublethal responses in fish as: a) behavioural responses (avoidance reaction; cough response), b) physiological responses (metabolic, locomotory, and activity patterns), and c) delayed effects (survival, growth and feeding, reproduction).

Examples of the potential sublethal impacts on British Columbia fish stocks are given below to illustrate the types of effects outlined by Patten (1977) and to identify inadequacies in current information.

### a) Behavioural Effects

The avoidance reaction of salmon fry to petroleum in seawater was examined by Rice (1973). Under laboratory conditions he demonstrated that pink salmon avoided the water soluble fraction of Prudhoe Bay crude oil in both freshwater and seawater. The avoidance threshold in seawater was considerably lower than in freshwater. Older fry showed a lower avoidance threshold than seawater adapted fry. Similar studies with other salmon species and life stages and under laboratory or "semi-natural" conditions have not been reported.

Evidence of the avoidance reaction of non-salmonid fish species is presented in a study by Kuhnhold (1972). In tests with Atlantic cod (G. morhua), Atlantic herring (C. harengus) and plaice (P. platessa) it was found that larvae exposed to three types of crude oils did not seem to be able to avoid oil contaminated water, especially dispersions, as their chemoreceptors were probably blocked or destroyed upon contact with oil compounds. Tests on larvae of species indigenous to British Columbia are lacking.

### b) Physiological Effects

The limited data which exist on the sublethal, physiological effects of petroleum on fish involve studies on the alteration of metabolic rates and locomotory and activity patterns. Changes which were noted include variations in oxygen consumption rates, impairment of swimming activity, and disruption of schooling behaviour. The significance of these changes remains to be determined.

### c) Delayed Effects

Delayed sublethal effects on survival, growth, feeding, and reproduction may have severe impacts on fish populations. For example, bioaccumulation of sublethal concentrations of hydrocarbons may cause reduced resistance to infection and parasitism, changes in reproductive capability, and increased susceptibility to predation in fish. Predators at the upper levels of the food chain may be particularly vulnerable to bioaccumulation (as are some groundfish species) because they feed on benthic species which may become contaminated from sunken oil. This contamination may remain in the sediments for extended periods causing chronic re-oiling (Scarratt, 1981). The non-selective feeding habits of juvenile sole and Pacific cod make them vulnerable to sublethal accumulation of oil (Westrheim, pers. comm., 1981). Another sublethal effect is the impact on survival due to the delay in production or the destruction of a food source due to oil contamination. As year class survival and strength is intrinsically tied to food availability, alteration of food resources may have major impacts, especially during critical life periods (e.g., pink and chum salmon fry at the time of ocean entrance (Parker, 1971) and groundfish larvae at the onset of feeding (Wilson, 1972)). The overall impact of an altered food source availability may be less than anticipated, however. The results of a Norwegian investigation have shown that this type of impact is insignificant in relation to the direct lethal toxicity effects of oil on larvae (Wiseman et al., 1981).

In general, the sublethal impact of petroleum on the behaviour, physiology, and ecology of fish is poorly understood. This is largely because of 1) variability within and among species, 2) variability of oils, and 3) environmental factors that affect both fish and oil. As was the case with the evaluation of the direct lethal effects of oil on fish, lack of local field verification of laboratory results exacerbates the problem of accurately predicting the sublethal impacts of oil on British Columbia marine fishes.

### iii) Direct Coating

A direct coating of oil on an organism may smother it causing death. However, because juvenile and adult fish have a mucilaginous coating, oil would likely be sloughed off, therefore having minimal impact. Eggs and larvae are susceptible to direct coating, especially herring eggs and larvae; starry flounder eggs; and English sole eggs, and larvae.

### iv) Incorporation

Incorporation of petroleum hydrocarbons into fish can occur through ingestion or absorption (Percy, 1981). This gives rise to two concerns, tainting and potential carcinogenicity, both of which adversely effect the utility of commercial species.

a) Tainting--There is some controversy over the magnitude of the impact of petroleum in water in regards to tainting in fish. Hyland and Schneider (1976) state that fish may become tainted in waters containing as little as 1 ppb petroleum, a level well within the range of oil concentrations found in close proximity to major oil spills (as documented by Neff _et_ _al_., 1976). Conversely Scarratt (1981) states that it is unlikely that fish will be tainted by oil in the water column except in restricted or shallow waters.

Tainting resulting from ingestion of contaminated food species is of concern, especially at the higher trophic levels where bioaccumulation and biomagnification may occur. Scarratt (1981) described an event where oil reaching the bottom in 35 m of water became incorporated into the clam _Macoma_ _baltica_. The flounder _Pleuronectes_ _flexus_, which preys on _Macoma_, was subsequently shown to have elevated body burdens of oil. Pathways of bioaccumulation are also discussed in Varanasi and Malins (1977).

b) Potential Carcinogenic Effects--may result from incorporation of petroleum hydrocarbons, specifically the polycyclic aromatic hydrocarbon (PAH) components. Fish have the ability to eliminate (depurate) PAH through enzymatic breakdown, a process which is induced upon oil contamination (Stegemen and Sabo, 1976; Varanasi and Malins, 1977).

Although fish may accumulate 200-300 times more hydrocarbons than the levels found in surrounding seawater, when they are placed in clean seawater, most of the accumulated hydrocarbons are eventually discharged, often within hours or one or two days. Investigations of the biological and physiological effects of bioaccumulated hydrocarbons are needed to provide a better understanding of the overall impact of oil on marine environments.

From a commercial fisheries viewpoint, oil incorporation into fish is a major concern because there are no established standards for rejecting contaminated catches aside from visible contamination.

v) Habitat Alteration

The effect of oil in altering fish habitat may have effects on benthic or benthic-adhesive egg laying species where a coating of oil would reduce or destroy the utility of that surface for egg deposition. Of particular concern would be the Pacific herring (C. pallasi) which spawns on marine plants, sea grasses, and rocks in the shallow nearshore waters (Hourston and Haegele, 1980) and lingcod (Ophiodon elongatus), which lay benthic egg masses in water from 0-20 m and have been known to spawn in the intertidal zone (Hart, 1973).

Our review of the literature has shown that marine fish species may be adversely affected by a major oil spill at all five impact classifications (i.e., direct lethal toxicity, sublethal effects, direct coating, incorporation, habitat alteration). In fact, it is possible that a post spill survey would show considerable numbers of dead, moribund or deformed, fish eggs, larvae and perhaps even juveniles and adults. However, present thinking states clearly that "it is very unlikely the effects of a single oil spill incident, however large, could be distinguished from natural variability with respect to recruitment in commercially important species" (CAFSAC, unpub.).

Inventory information is available for most finfish species which are managed for commercial harvest. The level of completeness varies but is generally better for those species which are of greater historical or economic importance. Herring and salmon have been studied in some detail; however, there are still major information gaps on juvenile and adult migration patterns and distribution. Knowledge of the location and distribution of groundfish spawning and rearing areas is poor as is information on ichthyoplankton.

Results of studies elsewhere in the world regarding the impact of oil exploration and development activities on fish indicate that large oil spills are a major concern. Preliminary assessment of the potential impacts on British Columbia fish resources of this type of event is severely hampered by the lack of information on the effects of hydrocarbons on indigenous fish species and by the limited knowledge on life history of important fish species, their interactions, trophic relationships and general ecology. If a major oil spill did occur it would be difficult to detect its impact on fisheries resources due to the large degree of natural variation in these biological systems.

The mobility of most adult fishes makes them less vulnerable to the direct lethal toxicity effects of oil pollution than egg, larval and juvenile stages. Commercial species assessed to have the greatest potential vulnerability were herring, English sole, starry flounder and lingcod. Avoidance behaviour is exhibited by some species, however further comprehensive studies of this behaviour are required.

Sublethal effects may be potentially more damaging than direct lethal toxicity but will be more difficult to assess due to the poor level of understanding of the detailed life history and ecology of commercial species. Studies should be formulated and undertaken to document species interactions and trophic relationships to provide sound knowledge on which to base sublethal impact assessment. Incorporation of petroleum hydrocarbons into fish may contaminate the flesh (tainting) and produce cancer causing agents (carcinogens). Fish purify (depurate) themselves within short time periods, however apart from visual presence of oil there are no established standards for rejecting contaminated catches. Direct coating of oil will do little apparent damage to fish because of their protective mucilaginous coating. High mortalities may occur to herring eggs due to suffocation. The effect of oil in altering fish habitat may have implications for species which spawn adhesive eggs, as the utility of a surface for egg deposition may be reduced or destroyed by a coating of oil.

The results of the Norwegian experience in the North Sea indicate that the effects of oil on fisheries resources will not be dramatic except possibly for a temporary decline in fishable stocks. However the number of unanswered questions, the resources at risk and the differences in the British Columbia situation warrant the application of all available safeguards.

### 3.3.6.7 Marine Birds

Of all marine animals, marine birds, particularly auks and seaducks, are most at risk from oil spills. Very extensive spill-related mortality of seabirds has been documented. Some seabirds, including auks, have very low reproductive rates. This limits the capacity of the population to recover after extensive adult mortality. As marine birds are a valuable wildlife resource their welfare must be considered when planning petroleum developments which may threaten their well-being.

There are several ways in which marine birds can be directly affected by contact with petroleum contamination. (After Holmes and Cronshaw, 1977).

These are:

i. Loss of buoyancy
ii. Impaired flight
iii. Loss of thermal insulation
iv. Ingestion of oil
v. Impaired ability to capture food or avoid predators
vi. Reduced reproductive potential

### i. Loss of Buoyancy

When seabirds become fouled with oil, air trapped between the feathers is eliminated. This and the added weight of the oil reduces buoyancy and can lead to death through drowning.

### ii. Impaired Flight

When flight feathers become contaminated, the birds ability to fly is reduced.

### iii. Loss of Thermal Insulation

Hypothermia can be a major cause of death in oil-fouled seabirds. Birds fouled with oil lose the air trapped between the feathers which leads to a loss of thermal insulation. In order to offset the increased loss in body heat, the metabolic rate has to increase. If the metabolic rate cannot keep pace with heat loss, death due to hypothermia will ensue.

Results from the work of Holmes and Cronshaw (1977) show that at 15°C, a black duck (*Anas rubripes*) fouled with 20 g (0.7 oz.) of oil had to nearly double its basal metabolism to offset heat loss. This rate equals that found in a normal black duck metabolizing at temperatures less than -10°C. Thus, even a moderately contaminated bird would have to double its food intake to achieve the level of metabolism necessary to offset the loss of thermal insulation. Considering that the foraging ability of oiled seabirds can be impaired, it can easily be impossible for oil-fouled seabirds to increase their food intake sufficiently to offset the fatal consequences of excessive heat loss.

Plate 11: The known vulnerability of Alcid birds such as the rhinocerous auklet to oil spills is a major concern (rhinocerous auklet).

*(British Columbia Provincial Museum photo)*

### iv. Ingestion of Oil

Ingestion of oil by seabirds can have a number of sublethal and lethal effects which could cause death. The toxic effect of oil ingested during the preening of oiled feathers can cause pneumonia, intestinal irritation, fatty livers, adrenal enlargement, pancreas dysfunction and toxic nephrosis of the kidneys (Hartung and Hunt, 1966). Peakall et al. (1981) indicate that small oral doses of oil causes a number of physiological effects in seabirds, including retardation of growth and impairment of osmoregulation and hypertrophy of adrenal and nasal gland tissue, apparently through the disruption of endocrine (hormone) balance. Whether or not these effects are lethal may depend on the physical state of the bird and on weather conditions. There is also evidence which indicates that ingested oil reduces egg production and hatchability of eggs (Grau et al., 1977, cited in Holmes and

Cronshaw, 1977). Autopsies on birds that died in captivity after the "Torrey Canyon" incident showed evidence of enteritis, infective arthritis, and aspergillosis, a fungus infection of the lung. Ingestion of oil by marine birds can contribute to their mortality during a spill.

### v. Impaired Ability to Capture Food or Avoid Predators

Increased body weight and impaired flight of oiled birds contributes to their exhaustion and may adversely affect their ability to forage or avoid predation. Field studies by Hawkes (1961), Hunt (1961), and Erickson (1963; as cited in Holmes and Cronshaw, 1977) have shown that oil contaminated birds become isolated from their food supply resulting in reduced food intake. Loss of foraging ability may be critical to birds suffering from exposure due to loss of thermal insulation.

### vi. Reduced Reproductive Potential

Seabird eggs contaminated with oil, most probably from oil-fouled parents, have a significantly reduced probability of hatching. Oil has been sprayed on eggs of gulls and cormorants as a means of bird population control with the effect that 90% of the eggs did not hatch. Albers (1977) coated mallard duck eggs with fuel oil and showed that the hatchability of oiled eggs was significantly reduced. Mortality from the coating of oil results because the exchange of gases through the shell is prevented (Hartung, 1965) or because the petroleum hydrocarbon toxins which penetrate the shell affect embryonic development (Albers, 1977; Szaro and Albers, 1977). These authors show that hatchability of mallard eggs is reduced when less than two percent of the surface is coated with 1 litre of number 2 fuel oil. Oil contamination of seabird eggs can contribute to the reduction of their reproductive rate. Extensive mortalities of seabirds have been documented following oil spills. The following tables by Vermeer and Vermeer (1975) list estimated mortalities sustained by seabird populations from oil spill incidents.

## TABLE 3.10

## DOCUMENTED BIRD MORTALITIES RESULTING FROM OIL TANKER ACCIDENTS

(After Vermeer and Vermeer, 1975)

| Year | Tanker and Location | Type of Accident | Estimated Oil Spilled | Estimated Bird Casualty | Predominant Victim |
|---|---|---|---|---|---|
| 1937 | Frank Buck, Francisco Bay, California, USA | collision | 11 800 tons crude oil | 10 000 | Common Murre |
| 1952 | Fort Mercer and Pendleton, Monomoy Island, Massachusetts, USA | break-up | 22 400 tons | >3 500 | Common Eider |
| 1955 | Gerda Maersk, Elbe Germany | grounding | 8 000 tons crude oil | 500 000 | Black Scoter |
| 1956 | Seagate (freighter) Olympic Peninsula, Washington, USA | grounding | undetermined | >3 000 | White-winged Scoter, Common Murre |
| 1961 | Poole Harbour, England | collision | 270 tons fuel oil | 150 (counted) | Grebes,<br>Red-breasted Merganser,<br>Shelduck |
| 1966 | Medway Estuary, England | valve open | 1 700 tons light crude oil | 5 000 | Black-headed<br>Great Black headed Gull |
| 1967 | Torrey Canyon, Seven Stones Reef, Great Britain | grounding | 100 000 tons crude oil | 30 000 | Common Murre<br>Razorbill |
| 1968 | Esso Essen, Cape Peninsula, South Africa | ramming | 4 000 tons crude oil | 1 250 (counted) | Jackass Pen<br>Cape Gannet |
| 1968 | Tank Duchess, Tay Estuary, Scotland | leaky hull | 87 tons crude oil | 1 400 (counted) | Common Eider |
| 1969 | Hamilton Trader, Liverpool Bay, England | collision | 700 tons fuel oil | 4 400 (counted) | Common Murre<br>Razorbill |
| 1969 | Palva, Uto, Finland | grounding | 150 tons Russian crude oil | 3 000 | Common Eider |
| 1970 | Delian Apollon, Tampa Bay, Florida, USA | grounding | 43 tons of oil | thousands | Loons,<br>Cormorants,<br>Mergansers,<br>Scaups |
| 1970 | Arrow, Chedabucto Bay, Nova Scotia, Canada | grounding | 10 000 tons Bunker C | 7 000 | Murres,<br>Dovekie,<br>Old Squaw,<br>Fulmar |
| 1970 | Irving Whale (barge), Newfoundland, Canada, | plug leak | 13-30 tons Bunker C | 5 000 | Murres,<br>Black Guillemont |
| 1971 | San Francisco Bay, California, USA | collision | 3 600 tons Bunker C | 20 000 | Western Grebe,<br>Surf Scoter,<br>White-winged Scoter,<br>Common Murre |
| 1972 | Dewdale, Cromarty Firth, Scotland | valve leak | 30 tons fuel oil | 1 000 (oiled but alive) | Pink-footed Goose |

## TABLE 3.11

## BIRD MORTALITIES RESULTING FROM OIL DISCHARGES OTHER THAN TANKER ACCIDENTS

(After Vermeer and Vermeer, 1975)

| Year | Location | Estimated Casualty | Predominant victim |
|---|---|---|---|
| Feb. 1945 | Apsheron Peninsula, Caspian Sea | 30,000 - 35,000 | Tufted Duck, Coot |
| 1952 | off Gotland, Baltic Sea | 35,000 | Oldsquaw Duck |
| 1954 | off Gotland, Baltic Sea | 10,000 | Oldsquaw Duck |
| 1955 | off Aland, Baltic Sea | 10,000 | Oldsquaw Duck |
| 1957 | off Gotland, Baltic Sea | 40,000 | Oldsquaw Duck |
| 1960 | Danish Archipelago | 20,000 | Black Scoter |
| 1962 | off Gotland, Baltic Sea | tens of thousands | Oldsquaw Duck |
| Feb.-Mar. 1969 | N. Sealand, Denmark | >10,000 | Common Eider,<br>Black Scoter,<br>White-winged Scoter |
| Dec. 1969 | Laeso-Vendsyssel, Denmark | >5,000 | Common Eider,<br>Black Scoter,<br>White-winged Scoter |
| Feb.-Mar. 1970 | east coast of Jutland, Denmark | >12,000 | Common Eider,<br>Black Scoter,<br>White-winged Scoter |
| Dec. 1970-Jan. 1971 | S. Kattegat, Denmark | >15,000 | Common Eider,<br>Black Scoter,<br>White-winged Scoter |
| Mar. 1971 | Djursland-Anholt, Denmark | 1,500 | Common Eider,<br>Black Scoter,<br>White-winged Scoter |
| 1969 | off Terschelling, North Sea | 35,000 - 41,000 | Common Eider,<br>Black Scoter |
| Nov. 1969-Mar. 1970 | around Great Britain | 14,000 | Common Murre |
| 1971 | Shetland Islands, Great Britain | 10,000 | Common Murre |
| 1959 | off southern Newfoundland, Canada | 12,000 (counted) | Common Eider |
| 1970 | Kodiak Islands, Alaska, USA | 10,000 | - |

Population studies show that oil pollution has caused substantial declines in marine bird numbers. Examples of population declines are from Holmes and Cronshaw (1977).

A large numbers of puffins from a colony of more than 100,000 members died in 1907 as a result of an oil spill on the island of Annet in the Isles of Scilly, about 22 miles from the Land's End of Cornwall, England (Mothersole 1910, cited in Holmes and Cronshaw, 1977). Other oil spills in the area have further depleted this colony until only about 100 puffins presently remain on Annet. Population studies at Sept Ile, Brittany (France) indicate that the "Torrey Canyon" incident (1967) reduced the number of breeding pairs of common guillemots by 81%, razorbills by 89%, and puffins by 84% (Monnat 1969, as cited in Holmes and Cronshaw, 1977).

Drastic population declines of common guillemots on Ailsa Craig, razorbills on the coast of Newfoundland and long-tail ducks migrating across Finland, have all been attributed to crude oil or petroleum product spills (cited in Holmes and Cronshaw, 1977). Oil spills pose similar threats to marine bird populations on the Pacific coast of Canada.

An index of sensitivity of seabirds to oil spills (Table 3.12) was devised by the Environmental Protection Service (1975):

TABLE 3.12

GROUPS OF BIRDS ACCORDING TO THEIR SENSITIVITY TO OIL SPILLS

| Rating | Species |
|---|---|
| 5 | alcids, seaducks |
| 4 | storm petrels, phalaropes, brant |
| 3 | loons, grebes, cormorants, kittiwakes |
| 2 | bald eagles, swans, diving ducks, shearwaters |
| 1 | gulls, dabbling ducks, snow geese, Canada |
| 0 | geese |

The vulnerability of seabirds to oil spills is a function of the behaviour of the species. Diving birds, such as auks (Alcidae family) and seaducks (scoters) are most vulnerable to oil spills because they spend most of their time on the water surface and dive, rather than fly when disturbed. They are the most prone to contacting a slick. Members of the Alcidae in British Columbia include the pigeon guillemot, Cassin's auklet, rhinoceros auklet, tufted puffin, ancient murrelet, marbled murrelet and common murre. This family is the most numerous breeding seabird in British Columbia (Table 3.5).

As auks have very low reproductive rates, decades may be required for replacement of populations that have suffered severe mortality (Vermeer and Vermeer, 1975). Most members of this family lay only one egg and take three years or more to reach sexual maturity. Furthermore, not all mature adults may breed every year (Holmes and Cronshaw, 1977). Some authors report survival of guillemots to the fledgling stage to be 0.2 individuals per breeding pair (Upenskii 1956 and Southern *et al.*, 1965, as cited in Holmes and Cronshaw 1977). Two studies cited by Vermeer and Vermeer (1975) state that thick-billed murres produce 0.4 young per pair (Tuck, 1957) and common puffins produce 0.6 young per pair (Nettleship, 1972). From this fledgling success data, Tuck (1961; as cited in Holmes and Cronshaw, 1977) and Leslie (1977; as cited by Vermeer and Vermeer, 1975) have estimated that it would take about fifty years for populations of alcids to double in number. It is clear that auks lack the reproductive potential to quickly replace losses after extensive adult mortality (Michael, 1977). A major spill or a number of successive spills could significantly reduce auk and seaduck populations in coastal British Columbia for decades.

Storm petrels are the second most numerous breeding birds on the British Columbia coast. They are less vulnerable to fouling from oil than auks because they spend more time in the air and dive only occasionally. Gulls are much less vulnerable to oil pollution at sea because they feed on the wing and spend less time on the sea than auks or scoters. Wading birds such as the great blue heron or sandpipers are normally only stained with oil so mortality due to oil pollution among this group is not likely to be high (Vermeer and Vermeer, 1975).

About one million migrant aquatic birds, mainly Arctic loons, sooty shearwaters and northern phalaropes, are temporarily vulnerable to oil pollution, particularly during the spring migration. During the fall and winter hundreds of thousands of waterfowl, primarily ducks and geese, rest and feed in protected inlets and estuaries, making them highly vulnerable to oil pollution. Vermeer and Vermeer (1975) caution that although auks and seaducks are most directly affected by oil, the ducks, geese and shorebirds that feed intertidally in estuaries may be hardest hit by oil pollution through destruction of their feeding habitat.

Millions of marine birds are vulnerable to oil pollution on the coast of British Columbia. They include marine birds in pelagic feeding concentrations, nearshore feeding areas, staging areas near breeding colonies as well as migrant aquatic birds.

### 3.3.6.8 Marine Mammals

Marine mammals can be affected by contact with oil or by ingestion of oil. Two species of marine mammals, the sea otter and the fur seal are very vulnerable to fouling by oil. Both of these species depend upon a thick fur coat or pelage of insulation against the cold marine waters in which they live. If the pelage is fouled with oil the insulative layer of air next to the skin is lost and water can penetrate the fur to the skin. This loss of insulating capacity increases heat loss from the animals which can easily cause hypothermia and death. Experiments with live muskrats, (McEwan, 1974) and sea otter pelts (Kooyman *et al*., 1977) show that heat loss from oiled animals is over twice that from unoiled animals.

Adult seals (other than fur seals) and sea lions rely extensively on blubber rather than fur for thermal insulation. Kooyman *et al*. (1977) have shown that oiling seal and sea lion pelts does not significantly increase their thermal conductance in water. No deaths due to hypothermia of oiled seals and sea lions are anticipated. Stellor sea lion pups, however, rely on a thick coat of fur for insulation until their blubber develops (Bigg, pers. comm., 1981). Even though pups can contact oil from oil-contaminated parents or from oil stranded in the intertidal zone, they would not likely suffer severe thermoregulatory stress because they do not enter the water until they are about two months old and by which time blubber is the primary insulation.

Harbour seal pups are born with no blubber and enter the water soon after birth. If contaminated with oil in the first few days after birth, they would be more susceptible to hypothermia than would the adults (Bigg, pers. comm., 1981).

All seals and sea lions in the vicinity of the Santa Barbara Channel blowout, including 34 California Sea Lions that were visibly oiled, appeared to be unaffected by the presence of the oil (Swift et al., 1970). A breeding rookery of elephant seals exposed to oil contamination during this incident also appeared unaffected (Le Boeuf, 1971). Some mortality of California sea lion pups was observed in the area but none of these was attributed to the presence of oil (Brownell and Le Boeuf, 1971).

Geraci and Smith (1976; cited in TMPL, 1980a) experimentally immersed ringed seals in oil and found that after 24 hours, the seals exhibited evidence of eye irritation including severe conjunctivitis, inflamed nictitating membranes, corneal erosion and ulcers. These symptoms cleared up after 20 hours in clean water, but the authors warn that permanent eye damage could arise from prolonged contact with oil.

Cetaceans such as whales, dolphins, and porpoises rely exclusively on blubber for thermal insulation so will likely not suffer hypothermia if they contact oil. However, the living cells on the nonkeratinized skin surface of these mammals can easily be irritated by noxious substances in petroleum (Geraci and St. Aubin, 1979; cited in Norton Sound 1981).

Plate 12: The true impact of oil on marine mammals has not been determined (Killer Whales, *Orcinus orca*).

*(Photo by Stafford Reid)*

Grey Whales appeared to avoid the Santa Barbara Channel oil slick as no oiled whales were observed during this incident and no whale mortalities were attributed to the blowout (Swift et al., 1970). The difficulty in accurately assessing the number of whales that were oiled or killed can lead to erroneous or misleading conclusions regarding the impact of an oil spill on these animals.

Even though there is some concern that spilled oil may plug the blowholes of cetaceans, the Norton Sound (1981) report maintains that such an event would be very unlikely. The exhalation of whales is very forceful, and "explosive", followed by an immediate inspiration and an abrupt closure of the blowhole (Geraci and St. Aubin, 1979; cited in Norton Sound, 1981). Such a breathing mechanism makes it very improbable that water or oil would be inhaled. The effects on cetaceans of inhaling volatile toxins from unweathered oilslicks are unknown (Norton Sound, 1981).

Seals, sea lions and sea otters can ingest oil while grooming or feeding, and can inhale the toxic, volatile fractions of unweathered oil. Smith and Geraci (1975, cited in Smiley, advance copy) believe that uptake of oil is largely through the skin or respiratory surfaces, suggesting that intake of hydrocarbons by inhalation can be substantial.

While ringed seals immersed in oil showed some kidney damage during studies done by Smith and Geraci (1975), "it is not known at what concentration detoxification by the liver or excretion by the kidney might fail." (Smiley, advance copy). Ringed and harp seals were fed oil-contaminated

Plate 13: Fur-bearing marine mammals such as the sea otter and fur seal may die from hypothermia if oil contacts their coat (Sea Otter, *Enhydra lutris*).

*(Ministry of Environment photo)*

fish in concentrations which probably represented the upper limit of what they might ingest from eating contaminated prey in the wild (Geraci and Smith, 1976). These authors concluded that neither harp seals nor ringed seals suffered permanent damage by ingesting oil during these experiments. There have been no similar experiments done on species of seals or sea lions that live in British Columbia, so the relevance of these studies to the British Columbia situation is largely conjectural.

As grey whales are benthic (bottom) feeders, they can ingest oil that has been incorporated into sediments or into benthic food organisms. Cetaceans, particularly those which are benthic feeders, have a poorly developed sense of taste (Tomilin 1955, cited in Norton Sound, 1981) so they may not avoid feeding on contaminated sediments. The baleen plates of whales that filter plankton may be fouled during an oil spill, resulting in decreased feeding efficiency (Norton Sound, 1981).

Populations of marine manmmals are most vulnerable when they occur in aggregations or have a limited distribution. The populations of harbour seals and most cetaceans are widely dispersed throughout the waters of coastal British Columbia. As an oil spill would affect only a small portion of the population, these species would not be endangered by an oil spill.

As the movements of whales becomes better known, areas of concentrations that are sensitive to oil spills may be discovered. Feeding concentrations of grey whales have been identified near Tofino on their southerly migration and near Cape Scott on their northerly migration. There have also been frequent sitings near Langara Island (TMPL, 1980a). If grey whales are vulnerable to oil slicks, it is in these aggregations that the population as a whole will be most endangered.

Steller sea lions breed at only three locations in British Columbia. Even though studies on similar species suggest that they are not vulnerable to fouling, extensive mortalities at any of these areas would have a severe impact on the population of Steller sea lions as a whole.

Although individual animals are frequently more vulnerable than general populations (Michael, 1977), there are periods when aggregations of mammals become highly vulnerable. An example of this would be the population of sea otters (approximately 100 members) which lives near Bajo Point and Bunsby Island, (northwest coast of Vancouver Island). This population would be endangered if an oil spill occurred in that area. The predicted impact (TMPL, 1980) would be major.

### 3.3.7 SUMMARY OF IMPACTS OF ROUTINE EVENTS ASSOCIATED WITH OFFSHORE HYDROCARBON ACTIVITES

#### Physical Presence of Offshore Platforms and Supply Vessels

The physical presence of offshore drill platforms represents a potential hazard only to marine birds, which have been observed flying into ventilation system intakes and into lit platforms at night. The magnitude of this impact is unknown. The presence of ships near sea lion rookeries is known to cause mass evacuations of the animals, therefore vessel traffic should avoid these areas.

Little information exists on the effects of ship offshore drilling rig noise on marine mammals. The information which is available indicates that caution should be exercised in locating vessel routes and rigs and that further work should be undertaken in this field.

#### Air Traffic

Air traffic and associated airborne noise has the potential to disturb cliff-nesting birds and reduce their reproductive success. Airborne noise may also disturb sea lions on established rookeries. These potential impacts are readily reduced by enforcing flight path minimum altitude requirements.

## Solid Waste Management

Solid waste from offshore rigs must be disposed of in designated land dumps to prevent the littering of fishing grounds and damage to fishing gear.

## Sewage Treatment and Disposal

While disposal of primary treated sewage should be examined on a site-specific basis it is generally not expected to have any adverse environmental impacts on the exposed well-mixed waterways which predominate the study area.

## Minor Fuel Spills

The impact of minor fuel spills in open, well-mixed waterways is expected to be localized, short-lived, and of minor environmental concern. Effects may be severe where continued spillage in a confined area leads to chronic pollution. Environmental impact assessments are required on a site-specific basis, taking into consideration protective measures for sensitive areas and areas with poor water circulation.

## Airborne Emissions

Airborne exhaust emissions from vessels and aircraft used in offshore hydrocarbon developments must comply with appropriate emission standards.

## Drilling Fluids and Drill Cuttings Disposal

Physical impacts resulting from the formation of a turbidity plume and the sedimentation of benthic inhabitants are not expected to be great. There is cause for concern from the chemical constituents (e.g., biocides and heavy metals) of drilling fluids which have, been shown to be toxic to marine organisms. Further work on potential impacts is required to evaluate the merits of marine disposal at a specific site, because of variability in the composition of drilling fluids.

### Submarine Pipeline Construction

Construction of submarine pipelines will affect marine benthic organisms along the pipeline corridor. While the impact is not expected to be great caution must be exercised when siting onshore approaches to avoid sensitive areas and to reduce sedimentation impacts on vulnerable species (e.g., herring spawn). Properly constructed pipelines are not expected to impede fishing operations.

### Ballast Water Discharge

Ballast water is a major source of petroleum contamination entering the world's oceans. Facilities should be provided at oil loading terminals for tankers to discharge contaminated ballast water.

### Formation Water Discharge

Standards limiting hydrocarbon levels in formation water discharges should be regulated and enforced to preserve water quality. Drill sites should be assessed on a site-specific basis prior to permitting discharge.

## 3.3.8 SUMMARY OF IMPACTS OF MAJOR OIL SPILLS ON MARINE BIOLOGICAL RESOURCES

### Marine Bacteria

Induction in the population growth of hydrocarbon utilizing bacteria occurs when petroleum enters the ocean. The magnitude and significance of this occurrence on the degradation of spilled oil has not yet been determined.

### Phytoplankton

The impact of spilled oil on phytoplankton communities is expected to be minor and of short duration. In general, when hydrocarbon levels are low, phytoplankton growth is enhanced and when hydrocarbon levels are high, growth is depressed. Species specific variations in tolerance to oil may lead to a shift in species composition with subsequent changes in the structure of the food chain.

Areas of sustained primary productivity will attract and support greater numbers of organisms from all trophic levels. As such, these areas may be used as indicators of sensitive oceanic areas requiring special attention during impact assessment for offshore oil production.

### Zooplankton

Laboratory studies have demonstrated the lethal toxicity of petroleum on zooplankton. Limited field observations have corroborated laboratory results, however more comprehensive field studies are required. The impact of oil spills in open ocean areas on zooplankton populations is likely to be undetectable due to the wide natural variability in zooplankton biomass. The adverse effects of a large spill in an enclosed bay, inlet, or sound during peak periods of productivity could be significant. Recovery of contaminated populations would be fairly rapid due to recruitment from unaffected areas.

### Marine Plants

Marine plants (including marine algae (seaweeds), saltmarsh plants, and seagrasses) are important primary producers in a food web which may be affected in varying degrees by petroleum contamination. Marine algae with a muco-polysaccharide coating (e.g., kelp) appear largely unaffected by oil, while those algal species without the coating (e.g., red algae) may experience large losses in population numbers. High mortalities of salt marsh vegetation and seagrasses following oil spills have been documented. Penetration and retention of oil in sediments of the low energy environments (e.g., estuaries) colonized by these species accounts for much of the mortality attributed to chronic contamination. These plants should be given maximum protection in planning for offshore oil production because of their importance as primary producers in the estuarine food chain and because of their relative vulnerability to oil pollution.

## Marine Invertebrates

The lethal toxicity of petroleum hydrocarbons to an array of marine invertebrates has been clearly demonstrated in laboratory studies. Post spill field observations have shown that given the right physical conditions, spilled oil may adversely affect intertidal, nearshore subtidal and subtidal marine invertebrate communities. Particularly vulnerable to direct toxicity effects are eggs and larvae because of their sensitivity and planktonic distribution in the water column. Intertidal species appear to be more resistant to direct toxicity effects than shallow nearshore subtidal species. However, intertidal species are more affected by the physical properties of oil (i.e., direct coating), especially species occurring in the high intertidal areas where oil may become stranded. Subtidal invertebrate communities may be adversely affected by chronic re-oiling from sunken oil trapped in the sediments. Incorporation of hydrocarbons into invertebrate tissues is a major concern as it may affect the physiology and behaviour of some species. Evidence strongly suggests that sublethal effects resulting from exposure to oil are potentially more disruptive than direct toxicity effects.

Following oil spills, high mortality rates has been observed for marine invertebrate species. Recovery of populations is fairly rapid due to natural dispersion during reproduction.

## Fish

Studies done elsewhere in the world regarding the impact of oil exploration and development activities on fish indicate that large oil spills are a major concern. Preliminary assessment of the potential impacts on British Columbia fish resources in the event of a spill is severely hampered by 1) the lack of information on the effects of hydrocarbons on indigenous fish species, and 2) the limited knowledge on life history of important fish species (i.e., their interactions, trophic relationships and general ecology). Given that a major oil spill did occur it would be difficult to detect its impact on fisheries resources because of the large degree of natural variation which occurs in biological systems. However, it is expected that herring, English sole, starry flounder and lingcod will exhibit the greatest vulnerability to oil.

## Marine Birds

Millions of marine birds in British Columbia are vulnerable to the direct effects of oil spills. They may be affected in one of the following ways: loss of buoyancy; impaired flight; loss of thermal insulation; ingestion of oil; impared ability to capture food or avoid predators; and reduced reproductive potential. The vulnerability of each seabird species to petroleum spills is related to the particular behaviour of the species.

Birds such as the alcids and scoters are extremely vulnerable to the effects of an oil spill because they spend most of their time on the water surface and dive, rather than fly, when they are disturbed. Compounding the problem is the very low reproductive rate of these birds, making recovery of an impacted population a slow process, often requiring decades. Of all marine animals, marine birds are most at risk from oil spills. The value of this resource must be carefully considered when planning for offshore petroleum development.

## Marine Mammals

Marine mammals of the British Columbia coast may be variously affected by contact with oil or ingestion of oil.

Sea otters, fur seals, and harbour seal pups are the most vulnerable of the mammals because oil contacting their fur pelage reduces or destroys its insulative properties and may lead to hypothermia and death. Adult seals, sea lions, and whales which rely on blubber for insulation appear unaffected by oil contamination.

Information on the effects of oil on marine mammals is sparse. More comprehensive investigation is required.

### General

Biological impacts of offshore hydrocarbon exploration and development have been extensively studied. The management of these impacts has been reported for many areas. This information can be effectively applied to the British Columbia situation. Chapter 6 attempts to draw conclusions from this information as it applies to the west coast of British Columbia.

# CHAPTER 4

# ONSHORE ENVIRONMENTAL IMPACTS

Susan Abs

# CHAPTER 4—ONSHORE ENVIRONMENT IMPACTS

## 4.1 INTRODUCTION

### 4.1.1 SCOPE OF CHAPTER

Offshore oil and gas development is supported by a variety of land-based services and facilities which are located in coastal areas adjacent to offshore fields. This chapter describes these onshore activities and their associated environmental impacts. It summarizes information about onshore development elsewhere in the world and highlights potential impacts on British Columbia coastal areas. The chapter includes information on impacts resulting from:

a) the onshore resource requirements of offshore facilities (e.g., fresh water use, waste disposal)
b) the construction and operation of onshore facilities (e.g., service bases)

Detailed assessment of potential onshore impacts is difficult because the location, size, and type of offshore reserves is unknown. However, British Columbia can use the information and expertise available in Canada and other countries to aid in the identification and management of environmental impacts. Experience gained in world production of offshore oil and gas is extensive: 35 countries produce crude and 23 of these also produce gas from offshore areas. Consequently, there is a large body of literature which addresses all aspects of the planning and management of offshore hydrocarbon production. Documentation of experiences in Alaska, the Shetland Islands (Scotland), Norway, California, New England, Atlantic Canada, and northern Canada is particularly useful to the British Columbia situation.

One of the common conclusions reached from experiences elsewhere is that the majority of impacts (both positive and negative) are felt in the coastal areas adjacent to the offshore fields (Brassard et al., 1981). In the past, planning has often focused on oil spill contingency planning with only minimal attention paid to environmental effects of routine operations both offshore and onshore. The key to minimizing the adverse impacts of offshore development will be comprehensive planning of routine activities.

There is a high degree of uncertainty regarding the environmental impacts of onshore activities. While facilities required in the exploration stage can be predicted to some degree, those which will accompany the exploitation of recoverable reserves depend on many factors. These include the location, scale, and timing of development, all of which depend on the nature of the reserves.

Plate 14: Environmental impacts of offshore hydrocarbon activities may affect other coastal activities such as fishing.

*(Photo by Susan Abs)*

The rationale for the conservation and protection of environmental resources (e.g., water, land, wildlife) is based on the three inter-related factors listed below. All three categories of resource values must be considered in assessing the specific impacts of offshore and related onshore hydrocarbon development.

1. Ecological Factors
   From an ecological perspective, management and protection of these resources is important for the preservation of biological systems diversity and integrity.
2. Commercial/Economic Factors
   Besides the inherent ecological value of resources, some wildlife and flora are commercially valuable and can be managed to enhance biological productivity for commercial use (e.g., fishing, hunting, aquaculture).
3. Social Factors
   Natural areas and wildlife have an important social value in providing a basis for nonconsumptive recreation and in enhancing the quality of life.

The following sections highlight particular onshore environmental concerns associated with offshore hydrocarbon development. Many potential impacts can be avoided or reduced through the application of existing regulations and the development of appropriate new planning and regulatory mechanisms. Close coordination of detailed environmental impact assessment with the assessment of social and economic costs and benefits will facilitate comprehensive planning.

### 4.1.2 DEFINITION OF ONSHORE FACILITIES

Onshore facilities can be divided into the following categories:

A. Direct Development - This includes facilities which are necessary for the exploration and development of the resource. Examples include helicopter pads and service bases.

B. Ancillary (Indirect) Development - This includes facilities which are not directly related to resource extraction but which provide services and materials required by the oil and gas industry. Examples include cement and marine repair companies.

C. Associated Development - This includes facilities which may develop due to the nature or location of the find. Examples are, partial processing plants or marine tanker terminals. Also included are facilities such as refineries and petrochemical plants which may benefit from siting near oil and gas activities.

D. Induced Development - This category encompasses developments which result from oil and gas-related activities. Examples include housing, road, and railway developments.

The environmental impacts of onshore facilities depend on: the scale of development which takes place, the number and types of facilities which are built, the location of the facilities, and the degree of existing development at the onshore servicing area. The phases of offshore development and associated facilities were described in Chapter 1.

## 4.2 GENERAL ONSHORE IMPACTS

Many of the impacts from onshore oil and gas facilities are similar to those associated with the construction and operation of other industrial facilities at coastal sites, (e.g., ports, dry-land log sorting areas). For environmental assessment purposes, a facility may be seen as several sub-projects, each of which consists of distinct activities. A particular activity may cause an environmental disturbance which, in turn, may have an ecological effect. An "environmental impact" results from the ecological effect. This breakdown of cause and effect can be illustrated with the following example:

Facility - marine terminal
Sub-project - berth construction
Activity - dredging

Environmental disturbance - increased turbidity
Ecological effect - smothering of organisms
Environmental impact - reduction in biological productivity
(Adapted from U.S. Department of the Interior 1978).

The following sections summarize the disturbances, effects, and impacts which can result from activities common to the construction and operation of oil and gas related facilities. More detailed environmental assessment is needed to identify the effects of these activities on resources of British Columbia. As with other coastal developments, many of the potential impacts can be avoided or mitigated with careful planning, design, and timing of facility construction.

### 4.2.1 CONSTRUCTION IMPACTS

The preparation of an industrial site involves many activities which alter the existing environment. The impact of this alteration depends on the scale and design of the facility, the sensitivity of the area, and the degree of any existing disturbance. Site-specific impact analysis must address both permanent habitat alienation and temporary disturbance resulting from construction. Site preparation can entail the removal of vegetation, land grading, filling and dredging. These activities can cause turbidity and sedimentation in coastal waters, change drainage and circulation patterns and alter fish and wildlife habitat. Marine service bases and other onshore facilities should be sited to avoid or limit dredging and construction in productive wetlands, estuaries, deltas and other sensitive areas. The following sections highlight the activities and potential impacts associated with facility construction.

#### 4.2.1.1 Vegetation Removal

Vegetation removal alienates or disturbs existing habitat. The net ecological effect depends on the significance of the resident community (e.g., presence of commercially or scientifically valuable species) and the availability of alternate habitat. In some cases, existing habitat will be replaced by a different, more exposed habitat.

#### 4.2.1.2 Terrain and Soil Disturbance

Terrain disturbance, soil removal, soil compaction and paving (along with vegetation removal) can alter the drainage patterns and water retention qualities of soil. Resulting disturbances can include increased run-off, soil loss, shore erosion, siltation or contamination of streams or waterbodies, land subsidence, landslides, seepage of contaminants into groundwater, and reduced groundwater replenishment. The latter is of particular concern in areas where salt water intrusion results in a reduction of the fresh water table in coastal areas. Reduced biological productivity in a particular community may result from a) decreased water quality, b) direct habitat alienation, and c) degradation or disruption of benthic, intertidal and freshwater habitats. Most of these impacts can be avoided or reduced using sound construction practices already instituted for road and industrial development.

#### 4.2.1.3 Air Emissions

During site preparation and construction, air emissions generated by incomplete combustion and fugitive dust from machinery and vehicles may contribute to air quality problems in the site area. Net air emission effects depend on existing air quality, local microclimate, and overall climatic conditions. However, they are usually insignificant or limited in area.

#### 4.2.1.4 Noise

The 24-hour operation of heavy machinery and the movement of helicopters, trucks, trains and boats increases noise levels in the area surrounding the site. The impact of noise from any particular facility depends upon the existing noise level, the characteristics of the area, and the properties of the sound. Generally, noise impacts may be more apparent in rural areas than in developed areas. The noise problem can be mitigated to some degree by the installation of various machinery silencers and noise mufflers as well as by careful site design and the use of vegetated buffer zones.

### 4.2.1.5 Solid Waste Production

Solid waste disposal from onshore facilities requires careful management. Solid wastes such as packaging materials will usually be burned, recycled or disposed of in a sanitary landfill. Special provision will be necessary to handle wastes such as paint or fuel. Solid waste disposal will be controlled by permit.

### 4.2.1.6 Dredging

Impacts of dredging are well known. Dredging a previously undisturbed estuary or harbour can have short or long-term impacts on the local aquatic environment. These impacts include:

a) the alteration of water circulation patterns and salinity profiles
b) the addition of particulates and nutrients to the water column (partly through increased turbidity)

Such changes in the aquatic environment may result in a partial or complete change in the species composition of the area. An initial reduction in overall productivity may occur as the food chain is reorganized. Benthic populations usually become reestablished after activities cease.

The net impact of dredging depends on the existing degree of disturbance and the characteristics of the biological community. While the direct impacts of dredging are less significant in an area which has been previously industrialized, problems may arise with the release of toxic or noxious substances from harbour sediments. Care must be taken in the disposal of any dredge spoils which are contaminated with industrial wastes, (e.g., metals or petroleum products). Dredging is now regulated under the Fisheries Act and the Ocean Dumping Control Act.

### 4.2.1.7 Filling

The filling of wetlands to create additional land can cause significant impacts including:

a) changing aquatic habitats to terrestrial ones
b) lowering biological productivity in the area
c) changing the water-retention properties of the filled area

The significance of these changes depends on the nature of the site. Freshwater and estuarine aquatic habitats and coastal mudflats are particularly sensitive and should generally be avoided. Filling is regulated by a variety of federal and provincial authorities.

#### 4.2.1.8 Wharves and Breakwaters

Wharves, breakwaters or other structures are often built along the foreshore in connection with harbour development. Such structures can alter longshore drift and erosion patterns and reduce water circulation in harbour areas. These alterations result in disturbances to existing biological communities and a decrease in water quality. The impacts of construction and the long-term effects of such structures should be addressed in the overall assessment of any proposed coastal facility.

#### 4.2.1.9 Facility Design

The aesthetic impact of an onshore facility will depend upon the nature and design of the facility, the site chosen and the site restoration and enhancement measures used. As many onshore facilities involve heavy industrial activities and 24-hour operation, lighting, odour and noise could be disturbing to adjacent human and/or wildlife communities. Facility siting and design which takes into account the natural setting and adjacent land uses minimizes such problems. The use of natural visual barriers such as hills and the use of vegetation buffers helps to mitigate visual impacts.

### 4.2.2 OPERATIONAL IMPACTS

The following sources of environmental disturbance are associated with the operation of onshore oil and gas related facilities such as service bases and processing facilities. As with the construction phase, the severity of impacts depends on the location, size, and design of the facility.

#### 4.2.2.1 Air Emissions

Under certain topographic and meteorological conditions pollutants may be trapped and concentrated. These emissions include the following materials:

i) Sulphur Dioxides developed from gas producing plants, refineries, fossil fuel combustion (boilers, compressors, trucks, autos, locomotives, boats, helicopters, cranes, etc.), and partial processing plants

ii) Particulate Matter developed from pipe coating yards, refineries, and various construction activities producing fugitive dust

iii) Carbon Monoxide developed from the combustion of fossil fuels in process machinery, refineries, and mobile sources such as helicopters, boats and highway vehicles

iv) Nitrous Oxides developed from fossil fuel combustion in process machinery, on and off highway mobile sources, refineries and partial processing plants

v) Photochemical Oxidants developed from fossil fuel combustion, incomplete combustion products, evaporation of petroleum products, and refineries

vi) Hydrocarbons developed from refineries, incomplete combustion products, evaporation of petroleum products, and partial processing plants

The dispersion pattern and the dilution rate of these air contaminants determines their ultimate impact upon the surrounding environment. The main factors to consider for minimizing atmospheric impacts are 1) the design of the plant, 2) the physical and chemical characteristics of the emissions, and 3) the physical and meteorological characteristics in the area (i.e., micro- and macro-climate).

Coastal British Columbia experiences relatively low mean ventilation rates, frequent overnight inversions and daytime inversions due to the presence of either marine strata or arctic air. Local topography encourages the establishment of closed circulation patterns in valleys or along coastlines (Fisheries and Environment Canada, 1978b). These factors render some areas of the coast sensitive to air pollution. Site-specific air analyses would be required prior to development of any major coastal facility in a sensitive area. All significant air emissions would be regulated through provincial permits.

#### 4.2.2.2 Waste Water Discharge

The potential environmental impacts of pollutants contained in waste water effluents are summarized in Table 4.1. The significance of these impacts is dependent upon the types of pollutants being discharged, their rate of dispersion and dilution, and the physical, chemical and biological characteristics of the receiving environment.

Although large accidental oil spills can occur at oil terminals, the more persistent threats to water quality are chronic discharges: effluents from sewage treatment, ballast treatment and cooling, and small discharges of crude oil or fuel. "Process waters" originate from almost all types of onshore facilities and may contain chemicals added during treatment or traces of the raw materials or end product. The chronic discharge of soluble hydrocarbons and other wastes from onshore facilities into adjacent receiving waters could impose long-term toxic effects on sensitive marine organisms. Adverse effects from effluents and spills can be averted by siting facilities in areas of low biological productivity, diversity and vulnerability. These should also be areas where effluents and spills can be easily managed. Spilled oil or fuel is most easily handled in well-protected harbours where containment equipment can be readily and effectively employed. Effluents are best disposed of in waters with high mixing energy such as the open ocean or inlets with swift tidal currents where pollution is rapidly diluted and degraded (Kramer et al., 1978). While most impacts from waste water discharges will be controlled through provincial permitting, the long-term impacts of continual low-level sources of water pollution over the 20-30 year life of the field may be of concern in coastal waters. Monitoring programs to measure cumulative effects on water quality would provide information needed to address potential problems.

## TABLE 4.1

## SUMMARY OF POTENTIAL IMPACTS OF POLLUTANTS WHICH MAY BE CONTAINED IN EFFLUENTS FROM HYDROCARBON DEVELOPMENT FACILITIES

**HYDROCARBONS** (in crude oils and petroleum products)

- contamination of seafood
- toxicity to many forms of marine fauna (particularly free-floating forms of ichthyoplankton) (see Section 3.3.6.3)
- illness after ingestion, and interference with feather function in birds
- adverse effects on photosynthesis and growth in marine plants
- reduced flowering and seed germination in marine plants
- selective inhibition of species in marine plants, phytoplankton, bacteria, and zooplankton

**HEAVY METALS**

- essential or non-harmful in minute concentrations, but are lethal to humans, animals, and plants in excessive doses
- build up to toxic levels in animal and human tissues

**AMMONIA**

- alters pH of receiving water
- toxic to pH-sensitive organisms
- increases plant growth

**SUSPENDED SOLIDS**

- reduction in photosynthesis due to increase in turbidity
- blanketing of stream bottom, lethal to eggs and young fish
- increase in substrates on bottom for bacterial decay

**ANTI-FOULING ADDITIVES**

- affect organisms in receiving water in manner of prescribed usage (e.g., algicide, bactericide, fungicide)
- lethal to other than target organisms

**THERMAL DISCHARGES**

- increases metabolic rate and bacterial growth rate
- alters animal behaviour, including feeding, spawning, migration, and predator-prey relationships
- decreases solubility of gases in water
- increases solubility of metallic compounds
- increases rates of chemical reactions and chemical toxicity.

(Adapted from New England River Basin Commission (NERBC), 1976)

### 4.2.2.3 Solid Waste Disposal

Two main types of solid wastes are produced from offshore and onshore facilities:

1. Non-Hazardous Wastes--These consist of such items as paper, packing material, scrap metal and wood products. These wastes cause minimal environmental impact, since they are usually incorporated into an existing landfill, recycled or incinerated.
2. Special Wastes--These consist of chemicals such as hydrocarbons, acids, heavy metals, and toxic chemicals. The most common of these wastes from oil and gas facilities are listed in Table 4.2. These compounds can lead to contamination of air, groundwater or surface water through seepage, run-off or evaporation if they are not properly contained or treated. In some European offshore oil and gas operations, private industries have been established to treat and dispose of these products (NERBC, 1976). In British Columbia, the Ministry of Environment (Waste Management Branch) has initiated the development of a comprehensive special waste management system for the province. As part of this program, proposals to build and operate special waste treatment and disposal facilities are being sought from the private sector. All waste disposal will be regulated by permit.

### 4.2.2.4 Onshore Contingencies

Since many onshore facilities involve the storage and handling of crude oil, natural gas, and processed petroleum products, there is a risk of leaks or spills from pipes and storage tanks. Associated with the possibility of leaks and spills is the risk of fire or explosion. Comprehensive leak and fire detection systems and thorough contingency planning will minimize this risk and reduce potential pollution problems. Voluntary adherence by industry to guidelines issued by the Petroleum Association for the Conservation of the Canadian Environment (P.A.C.E.) and the British Columbia Petroleum Association will also help to minimize risk.

## TABLE 4.2
## SPECIAL WASTES

| Source | Waste Description |
|---|---|
| Service Bases (brought in from offshore) | oiled drilling muds<br>oiled drilling bit cuttings |
| Marine Terminals | separator sludges<br>crude oil storage sludges<br>desalter sludges<br>settling pond scums or froth |
| Gas Processing Plants | spent caustic sludge<br>iron sulfide and spent wood shavings<br>filter materials with degraded amines<br>spent sieve materials<br>degraded solid dessicants<br>spent solid adsorbents |
| Oil Refineries | crude oil storage sludges<br>desalter sludges<br>separator sludges<br>settling pond scums or froth<br>spent alkylation sludges<br>biological waste sludges<br>slope oil vaccuum filter sludges<br>copper sweetening residues<br>catalyst fines<br>flocculent-aided precipitates |

(adapted from NERBC, 1976)

The principal regulatory authority for the design and use of storage facilities for petroleum products is the British Columbia Fire Commissioner. The National Fire Code of Canada 1977, adopted in 1980 by British Columbia, addresses potential environmental problems, particularly those related to dike design.

The Ministry of Environment can also influence the design and use of storage facilities in two ways:

1. Under Section 4 of the Environment Management Act, the Minister may

require that a proposed undertaking be modified to satisfy environmental concerns.

2. Under the new Waste Management Act, the Minister will be able to make orders regarding facility design and contingency plans.

#### 4.2.2.5 Operation of Service Vessels and Oil Tankers

Bilge water, which collects in the lower portion of boats, may contain toxic petroleum products and metallic components leaked from machinery. A 60 metre supply boat can generate 270 litres of bilge water per 24-hour-period (NERBC, 1976). This causes problems only if the water is discharged into a poorly-flushed area. If water quality problems are identified, waste water can be collected at the service base or marine terminal for treatment and removal of toxic substances before discharge.

Ballast water is carried in the hold of a supply boat or oil tanker to improve handling. Tankers discharge ballast water before arriving at the oil loading terminal. This water may become contaminated with oil if kept in the cargo storage compartments. The water can develop a high biochemical oxygen demand (BOD) and can contain high concentrations of fecal bacteria, heavy metals, and other pollutants. Any of these substances can be toxic to aquatic organisms and can contribute to pollution of harbour waters. The evolution of tanker design is towards ships which have the means to concentrate and remove oil or which use special tanks to separate ballast water from cargo residues. Such a design will reduce potential pollution problems.

A service boat generates approximately 135 litres per capita of sewage daily plus an equal amount of galley and sink waste water. Waste engine oil and frequent small spills of stores substances may also add small amounts of pollutants to harbour waters. Federal legislation (Canada Shipping Act, Ocean Dumping Control Act) limits discharge of all pollutants, except sewage, which is not covered under these statutes. These discharges will not pose a significant problem in areas where coastal flushing is rapid.

## 4.3 EXPLORATION PHASE

The exploration phase can be divided into two stages: seismic exploration and exploratory drilling (see Sections 1.1-1.3). Since the boats used in seismic exploration will likely use existing ports for berthing, repair and maintenance services, no significant onshore environmental impacts are anticipated during this stage. Exploratory drilling may have more significant onshore effects because facilities must be provided for servicing offshore rigs. Impacts will be reduced if onshore servicing is carried out at an existing port.

### 4.3.1 TEMPORARY SERVICE BASE

The temporary service base includes berthage for supply and crew boats, dock space for loading and unloading, helicopter landing pads, warehousing and open storage areas including bulk fuel storage, offices and accommodation for supervisory and communications personnel. The requirements for the base depend on the number and types of exploration vessels and drilling rigs being serviced. Sample requirements are as follows:

Land - 2-4 hectares on an all-weather harbour (warehouses - 0.2 ha/rig, open storage areas - 0.4 ha/rig, helipad - 0.4 ha/rig, plus land for operations, parking and office space)
Waterfront - 60 m of wharf/supply boat (total 120-180 m for one operation); 6 m water depth at pier
Fresh Water - 23.4 million litres/rig/year during drilling
Energy Needs - 12,800 barrels of fuel/rig/year for supply boats; 13,272 barrels of fuel/rig/year at drilling site
Solid Waste - up to 5.4 tonnes/day during drilling operations
Labour - 45 onshore service base jobs/rig serviced (NERBC, 1976)

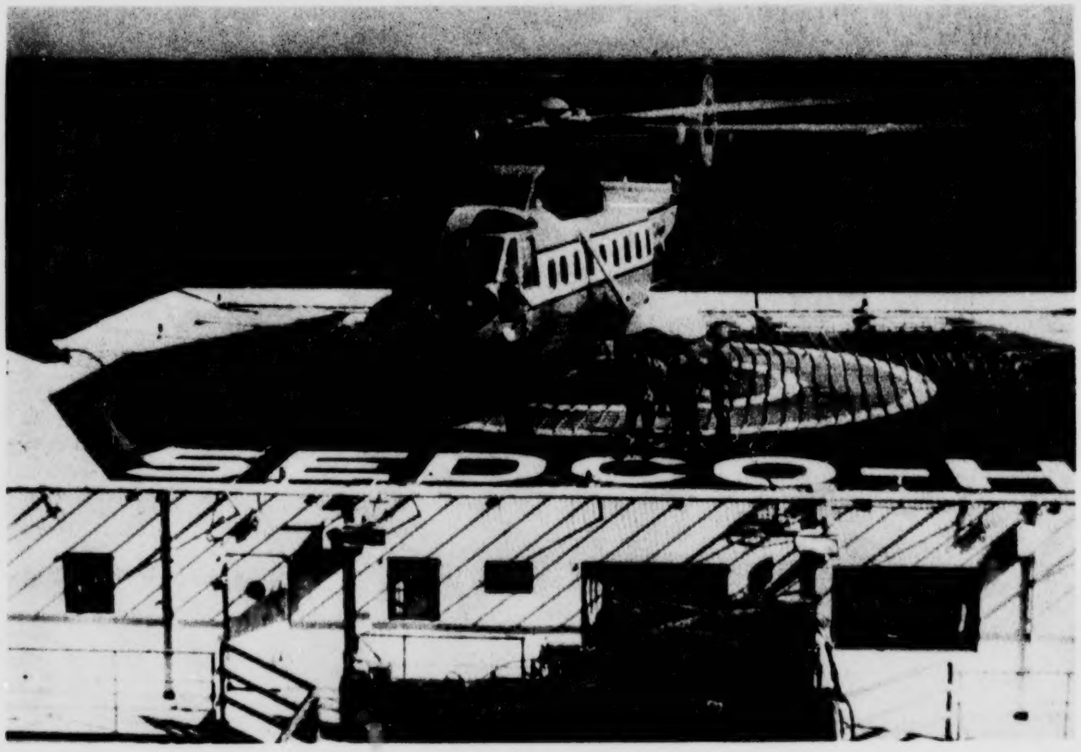


Plate 15: Helicopters are used to transport crew members and some supplies between the offshore drilling rig and the onshore service base.

*(Petro-Canada photo)*

An oil company will assess the suitability of potential sites for a temporary service base, based on the following factors:

- proximity to offshore exploration
- availability of water
- availability of industrially zoned land
- rail, road and airport transportation
- fuel storage facilities
- availability of waste disposal capacity
- local acceptance of oil industry related activities

(adapted from Office of State Planning, 1976)

In most cases, it is economically advantageous for the company to locate at an existing port. A temporary base which is independent from existing port infrastructure requires more storage and loading space and generates more helicopter and boat traffic than one at an existing port. Thus, it is also more likely to have significant environmental impacts, especially if a new site must be prepared.

For the northern British Columbia coast, the area of most interest for exploration, a Prince Rupert or Kitimat port would be the likely location for a temporary service base. Both have unoccupied industrially zoned land. Existing ports would have many of the marine repair and supply companies needed to service rigs and vessels. The service base must also have access to an airport for transportation of rig workers to homes outside of the drilling area during their time off.

There is a possibility that oil companies would use the Sandspit airport for crew transportation from drilling sites in that vicinity. Sandspit airport has more reliable air service than Prince Rupert where flights are often delayed due to inclement weather. Another community such as Sandspit, Port Alberni or Port Hardy could be used for a minor supply, service and transportation base if the weather seemed more reliable for helicopters or if the town is close to the drilling sites; this is unlikely during the exploration stage. Onshore environmental impacts will generally be more significant in a smaller, less-developed community than in an established port city.

Most of the impacts associated with the development of a service base are similar to those associated with any coastal industrial port development. Impacts can result from the following activities: (Section 4.2 outlines the environmental disturbances associated with these activities).

i) Site development - The service base is located at the waterfront because large amounts of materials must be transported to and from the offshore rigs. Preparation of a suitable area may include terrain disturbance, vegetation removal, pile driving, dredging, soil disposal, and filling. The severity of impacts from these activities depends on the design and size of the base, the sensitivity of the site and the degree of existing disturbance in the area. Any development which would involve disturbance of estuaries, salt marshes, bays, inlets, mudflats and beaches would be of concern. Siting of the temporary service base at an existing port or industrial area is preferred. The availability of gravel and sand for site development and the impacts of further extraction from local quarries and pits is a minor consideration.

ii) Water Use - An offshore exploratory rig can require 22.5 million litres of water per year (NERBC, 1976). This is not a significant withdrawal of freshwater and would not strain the supply of most British Columbia coastal communities.

iii) Waste Water Disposal - Sources of waste water at the temporary service base include sewage, vessel bilge and vessel ballast water. Two or three supply boats are needed for each exploration rig. Vessel wastes, along with stormwater run-off, can be the source of both groundwater and watercourse pollution. Appropriate regulation will minimize impacts from these sources. Current practice (at Valdez in Alaska and Sullum Voe in Scotland) requires all ballast water to be discharged to onshore tanks for treatment. Surface runoff at the base can be collected and treated before disposal to prevent entry of sediments and spilled contaminants into the harbour. (See Section 4.2.2.2).

iv) Solid Waste Disposal - Solid wastes are generated on the rigs, from supply vessels, and at the supply base. During drilling operations, approximately 5.4 tonnes per day of solid wastes are generated per well (NERBC, 1976). This includes non-hazardous wastes such as scrap metals, cables, spools, drums, cloth and packaging, and potentially toxic wastes such as drilling fluids, drilling fluid additives, bit cuttings, sand and sludges, galley garbage, lubrication oils, waxes and human wastes. While some wastes, especially the drilling fluids and bit cuttings, can be disposed of at sea under certain conditions (see Section 3.3.3.1), much of this waste will be returned to shore for disposal via the service base. Wastes produced at the base are less significant, amounting to about 180 tonnes/year (Colin Karasek Ltd., 1980). Toxic wastes must be transported to special facilities which employ various physical and chemical processes, and incineration to treat the wastes before disposal. Onshore waste disposal could be an issue of concern for municipal authorities, depending on the intensity of the drilling program and the size of the community.

v) Air Emissions - Combustion emissions, dust and noise which occur during construction from use of equipment and vehicles both on-site and on access roads, could result in localized impacts on air quality in areas of poor air circulation.

vi) Aesthetics - A service base has noise and light impacts similar to any 24 hour port/industrial activity. Decisions on base siting and design should consider these "nuisance" impacts on adjacent activities.

### 4.3.2 ANCILLARY INDUSTRIES

Many specialized ancillary industries (see Section 4.1.2), such as mud, cement and drilling tool companies, and boat repair and maintenance yards, will cluster in the vicinity of the service base to provide supplies, equipment and expertise for offshore and onshore activities. The types of additional development required will depend on the nature of the offshore operations. Individually, the requirements and impacts of these industries may be small. However, the cumulative impacts can be comparable to a large-scale marine industry.

Ancillary industries require considerable land in the vicinity of the service base. Industries such as mud and cement supply companies often require waterfront bases from which to supply the offshore rigs. Site preparation for these light industrial and commercial businesses may involve activities such as dredging, land fill, excavation and land clearing. The net environmental impacts will depend on the characteristics of the area. If existing industrial land is used, impacts would be minimized.

### 4.3.3 DRILLING SUPPORT VESSELS

Support vessels are needed to fulfill several functions during the exploration phase: supply, surveillance, towing, anchor handling, removal of wastes and crew transfer. Specialized boats which may be required include supply vessels, crew boats, seismic survey boats, diving support boats, firefighting boats and spill clean-up vessels. Most of these can dock at a berth of 70 m or less with a 5.5 metre draft (Colin Karasek Ltd., 1980). Routine operation of exploration rigs will require 2 or 3 supply boats making two trips per week to the rig. Helicopters, which are used to transport those supplies, crew and materials which are needed promptly, make one to two trips per day from the service base to the rig. The number of ship and helicopter trips will depend, in part, on the distance to the rigs.

Support vessels will be a source of sanitary wastes, oily bilge water, ballast water and tank washings (see Section 4.2.2.5). Impacts from helicopter noise are described in Section 3.3.2.1.

### 4.3.4 INDUCED DEVELOPMENT

A large exploratory rig will employ 120-175 workers offshore and onshore. While most of the 65-85 rig workers will not reside in the area during the exploration stage, some or all of the base workers will. The need for additional housing, roads and services will depend on the number of new people who come in to fill the service base jobs.

Impacts can result from environmental disturbance due to the development of additional housing and roads and from the expansion of community services and solid and sanitary waste facilities. For a one-rig exploration operation, environmental impacts resulting from increased population would not be significant in a larger community. Growth of smaller communities could have more apparent environmental disturbances.

## 4.4 DEVELOPMENT PHASE (CONSTRUCTION/PRODUCTION)

Extraction and processing stages may not immediately follow the location of a recoverable reserve of oil and/or gas. Factors which will determine the timing of resource development include: current markets for oil and gas, company priorities, regulations and planning guidelines. Most of the activities which occur during development drilling are expansions of those which take place during exploration. The initial construction phase will be the period of most intense onshore activity as the need for more berth space, storage yards, heliports, etc., increases (Figure 4.1). This

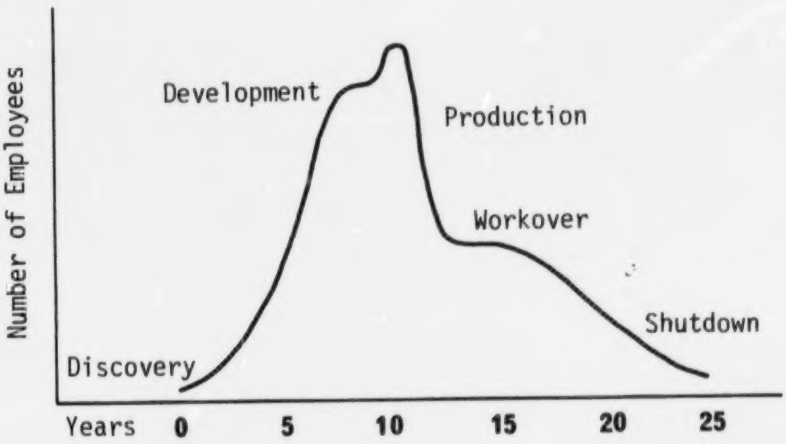


FIGURE 4.1

**REPRESENTATIVE PATTERN OF OFFSHORE HYDROCARBON DEVELOPMENT**

(Massachusetts Office of State Planning 1976) is also the period for construction of the pipeline and/or marine terminal and other processing and ancillary facilities. The following sections outline potential onshore environmental impacts during construction and production stages. A site-specific examination of potential service base sites in British Columbia would be necessary for a more definitive analysis.

### 4.4.1 PERMANENT SERVICE BASE

An oil company will usually expand its temporary service base to create the permanent service base. A new base is only established if expansion of the temporary base is limited by insufficient backup acreage or dock space, or if the distance to the offshore field makes it economically attractive. A small base for crew transport and some supply transfer could be developed at a site closer to the drilling activity. Direct sea transport of some materials or equipment from suppliers to rigs (e.g., piping) would reduce space requirements at the onshore base.

On the north coast of British Columbia, Prince Rupert and Kitimat offer sites which could be suitable for a temporary base and have room for expansion to a permanent base. Prince Rupert and Kitimat are the only mainland port cities which are connected to road, rail and air transport systems and have extensive industrial infrastructure. Port Hardy or Port Alberni are possible main or secondary base sites, but this is unlikely since all materials would have to be brought to Vancouver Island.

Impacts associated with the construction of a permanent service base and associated facilities are similar to those resulting from construction of a temporary base, but can be more significant due to the increased intensity and scale of activity.

Sample requirements for a permanent service base are as follows:

Land - 20-30 hectares on an all-weather harbour (permanent offices - 900 sq. m, helipads - 0.4 ha/platform, plus warehouses and open storage)

Waterfront - 60 m of wharf/supply boat (2-3 boats/platform); 6 m water depth at pier

Fresh Water - 36,900,000 litres/platform/year during development drilling with very little during production

Energy Needs - 12,800 barrels of fuel/platform/year during development, 19,200 barrels of fuel/platform/year during production

Solid Waste - 5.4 tonnes/day during drilling

Labour - 50-60 onshore service base jobs/platform serviced

(NERBC, 1976)

In addition to the activities associated with the construction and operation of a temporary base (see Section 4.3.1), sources of air emissions during permanent service base operation include evaporation from storage tanks and fuel transfer. The impact on air quality depends on the number of storage tanks and vehicles in use as well as ambient air conditions.

Pipeline construction and installation companies usually set up their own service bases. These bases have requirements and impacts on a scale similar to those of the temporary service base and may also be temporary, depending on the scale of offshore development.

### 4.4.2 TRANSPORTATION SYSTEM

Offshore reserves are brought to shore by pipeline or a tanker/barge system. A marine pipeline system consists of a pressure source, gathering lines, a submerged pipeline and a landfall site. A tanker or barge transportation system consists of offshore storage and loading facilities, tankers or barges, and a marine terminal for unloading (see Section 1.8). Mixed pipeline/tanker transport systems can also be used. A tank farm for onshore oil storage is usually part of the transport system. Approximately 98% of the oil and all of the gas produced on the U.S. outer continental shelf is transported to shore by marine pipeline, since pipelines are safer and can provide continuous gas and crude oil transportation, free from interruptions due to poor weather. In the North Sea fields, more offshore storage and loading of tankers occurs.

### A. Pipeline

If a marine pipeline is used, it may connect to an overland pipeline which transports oil or gas to inland refineries and processing facilities. Pumping stations, tank farms and processing facilities may be located in the vicinity of the landfall. The marine pipeline is usually built along the shortest route between the production platform and the shore. In British Columbia, this could result in the siting of the landfall and other facilities in a small community or undeveloped area where impacts may be more significant than at a developed port. Facility construction should be avoided in biologically sensitive areas.

Pipeline construction can result in environmental disturbance from the following activities: (Section 4.2 describes the environmental impacts of these activities)

i) Site Preparation - The degree to which onshore pipeline construction activities will disturb terrain, soils, vegetation, and wildlife will depend on the nature of the route. Impacts of pipeline construction are often temporary, although erosion of disturbed soils can be a persistent problem on slopes. Impacts can be significant where pipelines cross watercourses, flood plains and wetlands. Aquatic and terrestrial habitats along a pipeline can be adversely affected by disturbances such as disruption of soils leading to erosion and downstream sedimentation. Many of these impacts can be mitigated or localized through careful planning and the use of special construction and restoration techniques.

ii) Air Emissions - Pipelines can produce air contaminants such as sulphur dioxides, hydrocarbons and nitrous oxides from a variety of sources such as compressors, pumping stations and leaks from valves and seals. However, the overall impact of normal pipeline operations on ambient air quality appears to be minimal (NERBC, 1976).

## B. Marine Terminal

A marine terminal may be needed at the onshore base or elsewhere along the coast to serve any of the following functions:

- to load crude oil received by pipeline from offshore into tankers for delivery to refineries
- to receive crude oil from tankers or supertankers for delivery by overland pipeline to nearby refineries (tanker shipment of oil may be necessary if there are a large number of scattered production fields which do not justify construction of a pipeline)
- to receive refined petroleum products for storage and delivery to overland markets

Facilities at a marine terminal are similar to those at any port (i.e. wharves, berths, back-up land, equipment, warehousing and storage areas). Ballast treatment facilities, bunker fuel storage, and partial processing facilities may also be required. Extensive storage tank areas are needed above ground or underground for partially processed oil and/or liquified gases.

Depending on the location of a find in British Columbia, oil could either be shipped to lower mainland terminals, which are already served by marine terminals, or inland. There are few sites on British Columbia's coast which have the naturally sheltered deep waters, sufficient back-up land, power and water supplies necessary to support a new marine terminal. Such a facility would most likely be located near an existing port. Environmental impacts could result from the following activities: (Section 4.2 describes the effects of such activities).

i) Site Preparation - Impacts of site preparation for a marine terminal would be similar to those associated with construction of the permanent service base. Dredging, filling and wharf building may alter the shoreline extensively, directly affecting aquatic habitat and changing shoreline erosion/accretion patterns. Less dredging is required for fixed offshore piers, but the connecting pipeline to shore may cause some environmental disturbance.

ii) Air Emissions - Air emissions during terminal operations are similar to those at service bases, but levels are high due to extensive oil and gas handling, storage, and possible processing activities. Sources of air emissions at the terminal include: evaporation from storage tanks and transfer of crude and fuel; combustion products from process machinery and marine vessels; and accidental spills and leaks. Careful siting helps to avoid most problems. Air quality monitoring before and after construction would indicate pollution problems to be addressed.

iii) Waste Water Discharges - As with service bases, waste water from terminal operation can pollute local waters. Waste water sources include domestic waste water, bilge water, ballast water, cooling water, boiler water, process water and stormwater run-off (see Section 4.2.2.2).

iv) Waste Disposal - Oil-contaminated solid wastes from terminal operation are a major component of the total volume of solid waste generated by a marine terminal. Quantities of chemical waste slurries may also be produced. Environmental impacts of waste disposal can be managed if adequate treatment and handling facilities are used. In order to minimize water pollution, special clean-up procedures would be needed for small oil spills and leaks at the terminal facility and during oil transfer between tanker and shore.

### C. Oil Storage Facilities

Tank farms are associated with most oil transport systems. As these facilities are often located in coastal lowlands which are sensitive to air and water pollution from spills, leaks or emissions they should be sited so as to avoid areas with geologic hazards such as landslides, seismic activity, flooding and soil liquefaction. Diking of the area is required in order to confine oil spills in case of a leak or rupture. Pollution control devices can significantly reduce vapour loss from onshore storage, but impacts of residual emissions should be taken into account as a major factor in tank farm siting.

### 4.4.3 ANCILLARY INDUSTRIES

Ancillary development in this stage would be an expansion of those activities described in Section 4.3.2.

### 4.4.4 INDUCED DEVELOPMENT

A development drilling rig will employ approximately the same number of workers as the exploration rig but onshore jobs will increase slightly. As in the exploration stage, many rig workers will commute to homes away from the onshore base. More significant will be population growth due to the influx of workers for construction of onshore facilities. Population multipliers for the development (construction) stage in eight United States examples ranged from 1.68 to 4.3 depending on the size of the community, existing development levels, and workforce (Zinn, 1978).

The environmental effects of residential and commercial growth induced by oil and gas development could be significant in a coastal British Columbia community. Forecasting errors have often led to underestimations of the expected growth in population, labour force, housing and other oil-induced activities. The net result of this has been unanticipated environmental impacts for which communities were not prepared (Nelson and Jessen, 1981). Impact assessment at the pre-development stage must include discussion of induced growth and its impacts. Provision can be made to detect and manage unexpected impacts through a monitoring program which measures impacts throughout the life of a project.

Plate 16: A facility for drill rig servicing and repair is one of the onshore facilities which could be built during the development stage (Peterhead Scotland).

*(Photo by Robert Fraser)*

### 4.4.5 ASSOCIATED FACILITIES

The degree of development of associated facilities (see Section 4.1.2) is highly uncertain, depending on factors such as the type of oil and gas produced, location and size of the find, markets for petroleum products, and economic factors. Some of the most significant long-term environmental consequences of offshore oil and gas development can result from the cumulative effects of various associated developments. The following summaries of the requirements and impacts of such activities indicate the range of potential onshore facilities.

#### 4.4.5.1 Partial Processing Facilities

Partial processing removes impurities from a crude oil well stream.

The type of processing system will depend on the distance between the platform and shore, the well stream characteristics, the transportation system and the costs of various options. Some processing will occur offshore and some will take place onshore. Separation of natural gas from oil is the simplest process and usually takes place at the platform.

A partial processing facility may be located near a marine terminal and/or gas processing facility or it may be situated at a separate coastal site or further inland. Facilities can include a pipeline feed or marine terminal, oil storage tanks, oil and gas processing and treatment, liquified petroleum gas storage and ancillary activities. Sample requirements of this facility are as follows:

Land - 6 hectares per 100,000 barrels of oil and associated gas to be processed
Water - 4500 litres per month
Energy - 1.5 million SCFD/month gas; 400,000 kwh/month.
Labour - 150 construction field jobs (for oil and gas facilities); approximately ten jobs during operation.
Construction Period - 15 months

(NERBC, 1976)

Activities associated with partial processing plants are similar to those of service bases and marine terminals. Impacts can result from site preparation, noise and air emissions, waste water disposal, solid waste disposal and 24-hour lighting and noise. Air emissions include evaporation emissions from surge and storage tanks, combustion emissions from process machinery and leakage from valves and seals. Impacts from these emissions can be reduced with careful facility design and siting. As the danger of fire exists at any facility where quantities of petroleum are stored, stringent precautionary and emergency measures are necessary at the site.

Process water, which is produced as a result of the oil and water separation process, often contains high concentrations of suspended and dissolved solids, heavy metals, and dissolved salts and oil. Treatment removes many of these pollutants, but residual pollutant levels must be considered when disposing of treated water. Cooling water is required for pumps and other machinery. Discharges of this heated water, especially when combined with those from other facilities, can cause net increases in the temperature of the receiving water thus affecting aquatic habitats. Disposal of these waste waters is regulated by existing provincial legislation.

Other by-products of partial processing include solid combustible materials and special wastes such as sedimented materials, sludge, scums and froth from treatment of crude oil or brine. If these wastes are properly treated and disposed of, they will not cause water quality problems in surface waters or watercourses.

### 4.4.5.2 Gas Processing and Treatment Plants

After gas is separated from the oil and water of the well stream and treated to remove impurities (partial processing), it may be further processed to recover valuable liquid hydrocarbons. It would then be delivered to a connecting gas transmission line or further processed into petrochemicals or liquified natural gas (LNG). The type of gas processing depends on chemical composition of the gas, size of the gas find, expected production rate, location of partial processing facilities and the market for liquid hydrocarbons. Sample requirements for a billion cu. ft./day processing plant (an LNG plant would have different requirements) are as follows:

Land - 20-30 hectares for buildings, storage facilities, pipes, towers, compressors, parking lots and buffer zones
Water - 900,000 litres per day (average)
Energy - 5,400,000 kw hours/month;
10,800,000 cubic metres/month of gas from the plant
Labour - 550 construction jobs (peak figure)
45-55 operation and maintenance jobs
Construction Period - 1-5 years

(NERBC, 1976)

The gas processing facility must be located somewhere between the marine pipeline landfall and any further gas transmission line. A coastal site is usually preferred, although high land costs and land use controls can make an inland site necessary.

Many of the impacts of gas processing will be similar to those from partial processing (see Section 4.4.5.1). The magnitude of impacts will depend upon volume of gas processed, raw gas composition, plant design and pollution controls. Activities and waste by-products could be managed through existing regulations.

### 4.4.5.3 Refineries

A refinery may be built to process oil from offshore reserves if the distance to existing refineries is great and there is a market for refined petroleum products. Construction of a refinery in association with British Columbia offshore development is not likely. If an oil refinery is proposed, stringent environmental regulations will influence site selection. Since oil refinery siting is often controversial, refiners tend to avoid environmentally sensitive areas and communities which are unfavourable to industrial development.

### 4.4.5.4 Petrochemical Plants

The discovery of commercial quantities of offshore oil and gas may provide incentive for petrochemical development. The key factors influencing the establishment of a petrochemical industry are: the availability of sufficient and reliable gas supply, the existence of infrastructure and access to product markets. There is already a natural gas surplus in British Columbia. If a petrochemical industry has not already been developed by the time that an offshore find is made, the discovery of further reserves may make the industry more attractive.

Environmental impacts associated with a petrochemical plant will vary greatly, depending on the specific nature of the facility and its location. Impacts are similar to other coastal industrial facilities (Section 4.2).

Petrochemical facilities have high labour requirements which would lead to population growth and related urban development. This growth could have significant environmental impacts in a British Columbia coastal community. Secondary industry which develops from petrochemical processing would add to these impacts. Careful site selection would help to reduce impacts. British Columbia does not have standards or objectives for waste streams from petrochemical plants. As there are currently several proposals for such a facility, the Ministry of Environment is taking steps to gather the information needed to assess and regulate this type of development.

#### 4.4.5.5 Platform Fabrication Yards

A fabrication company makes the decision to establish a new production platform fabrication yard only after a significant find has been made and production plans are set. For the Alaska fields, concrete platforms (see Section 1.13.2) will be fabricated at the nearest feasible onshore site; however, steel platforms, which are necessary for seismically active areas, must be assembled in west coast U.S. ports or Japan and towed to Alaska. A similar situation can be expected for British Columbia. Concrete platform fabrication must take place at a waterfront facility which is similar to a ship-building yard and drydock. In some cases, offshore deepwater construction sites have been used for platform assembly. A platform fabrication yard need not be near other onshore facilities but could be at any coastal port which has basic services.

The impacts associated with a platform fabrication yard would be similar to those associated with the permanent service base.

#### 4.4.5.6 Pipe Coating Yards

Pipe is needed for the small-diameter pipelines which join numerous wells to the platform and for the large-diameter pipelines which transport oil or gas to shore. Two or three firms may establish yards to handle the varying sizes of pipe. The yards are usually located near the rig servicing base and pipe-laying service base. Approximately 95% of the 40 to 60 hectares required for a permanent yard is for pipe storage.

Impacts of such a facility will be similar to those from a service base or other onshore industrial facility. The most significant requirement of this facility is the need for a large parcel of waterfront land.

## 4.5 CONFLICTS WITH EXISTING COASTAL ACTIVITIES

Offshore oil and gas activities are expected to occur in northern British Columbia, which is not subject to as many competing coastal demands as the more heavily used southern British Columbia coast. However, these northern areas provide the basis for many coastal activities such as commercial, native and recreational fisheries, aquaculture, shipping, forestry, recreation, tourism, and special interest sites (i.e., archaeological, ecological, and heritage sites).

Offshore hydrocarbon development may have impacts on these activities either directly, through environmental damage from spills, blowouts or routine operations or indirectly, through competition for scarce resources. For example, the need for flat, well-drained land for onshore facilities may put pressure on scarce coastal areas such as estuaries and coastal lowlands which are important to fishing and recreation.

Impacts on existing activities can result from "fundamental" or "nuisance" factors (Draper, 1981). Fundamental damage results if resources which are considered crucial to a particular activity are damaged or destroyed (e.g., a fish kill due to a major spill). Nuisance factors have an incremental effect on the viability of an existing activity (e.g., fishermen may lose fishing gear due to underwater debris). Mitigation and compensation programs could address some of these impacts.

Since the economy of coastal British Columbia communities is presently based on these activities, any impacts of offshore development would be of concern. Potential conflicts with other activities, although difficult to assess, should be included in any comprehensive analysis of hydrocarbon development. Both measurable (dollar value) and intangible (scenic, heritage) values should be included. As there is potential for expansion in most of these resource sectors, the effects of offshore hydrocarbon development on future opportunities must also be examined (i.e., what options will be eliminated in these sectors if offshore development proceeds)?

The following activities should be considered in the detailed impact assessment of offshore petroleum development.

### 4.5.1 FISHING

Impacts of offshore development on fishing activity could include direct pre-emption of small areas of fishing grounds, damage to fishing gear and nets from offshore structures, service boats and debris on the seafloor,

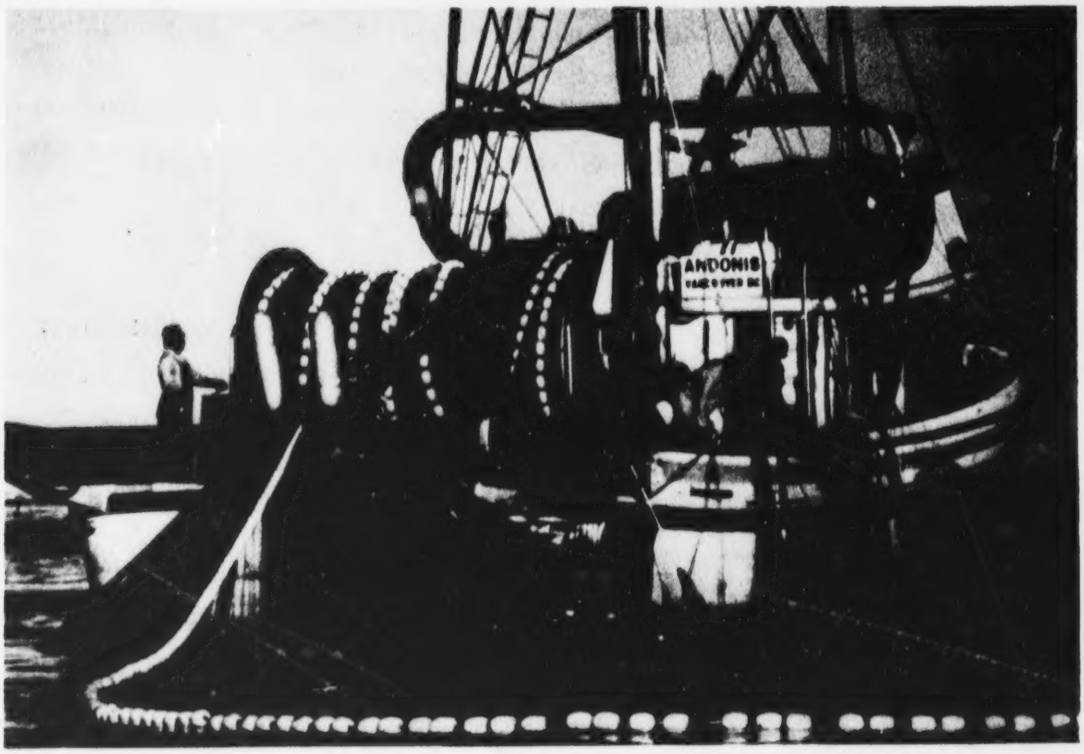


Plate 17: Environmental impacts of offshore hydrocarbon development on coastal resources could affect existing coastal activities such as fishing.

*(Ministry of Environment photo)*

and effects of spills on fish productivity (see Section 3.3.6.6). Gear conflicts can be handled if netting and longline areas are identified and vessel traffic corridors are designated to avoid these areas. Some preemption of fishing areas may be unavoidable. Involvement of fishermen's organizations in planning will help to identify potential problems. Conflict arbitration and compensation systems can be developed to address any problems which are identified.

### 4.5.2 RECREATION AND TOURISM

Offshore oil and gas development has the potential to affect recreational activities associated with coastal waters and shorelines. These activities include boating, fishing, beachcombing, hiking, camping, hunting, bird-watching, wildlife-watching, and sightseeing at special interest sites such as hotsprings and archaeological/heritage sites. The recreation and tourism potential of the Queen Charlottes and the North Coast is relatively undeveloped due to low human population, limited road access and limited tourist facilities. However, since the Prince Rupert area is a key transportation interchange for the British Columbia Ferry System, the Alaska Marine Highway and the Yellowhead 16 Highway, this area has the potential for further development. Ferry service has recently been restored to the Queen Charlottes, providing regular vehicle access to the area. Recreation and tourism on the Queen Charlotte Islands is growing, particularly in the South Moresby area. In 1981 eighteen different companies or recreational charter firms provided trips into that area. Recreational use of the west coast of Vancouver Island is concentrated in the southern half of the island, with access from Port Alberni or Victoria. All of these regions have considerable potential for increasing their contribution to provincial tourism (pers. comm., Tourism B.C., 1981).

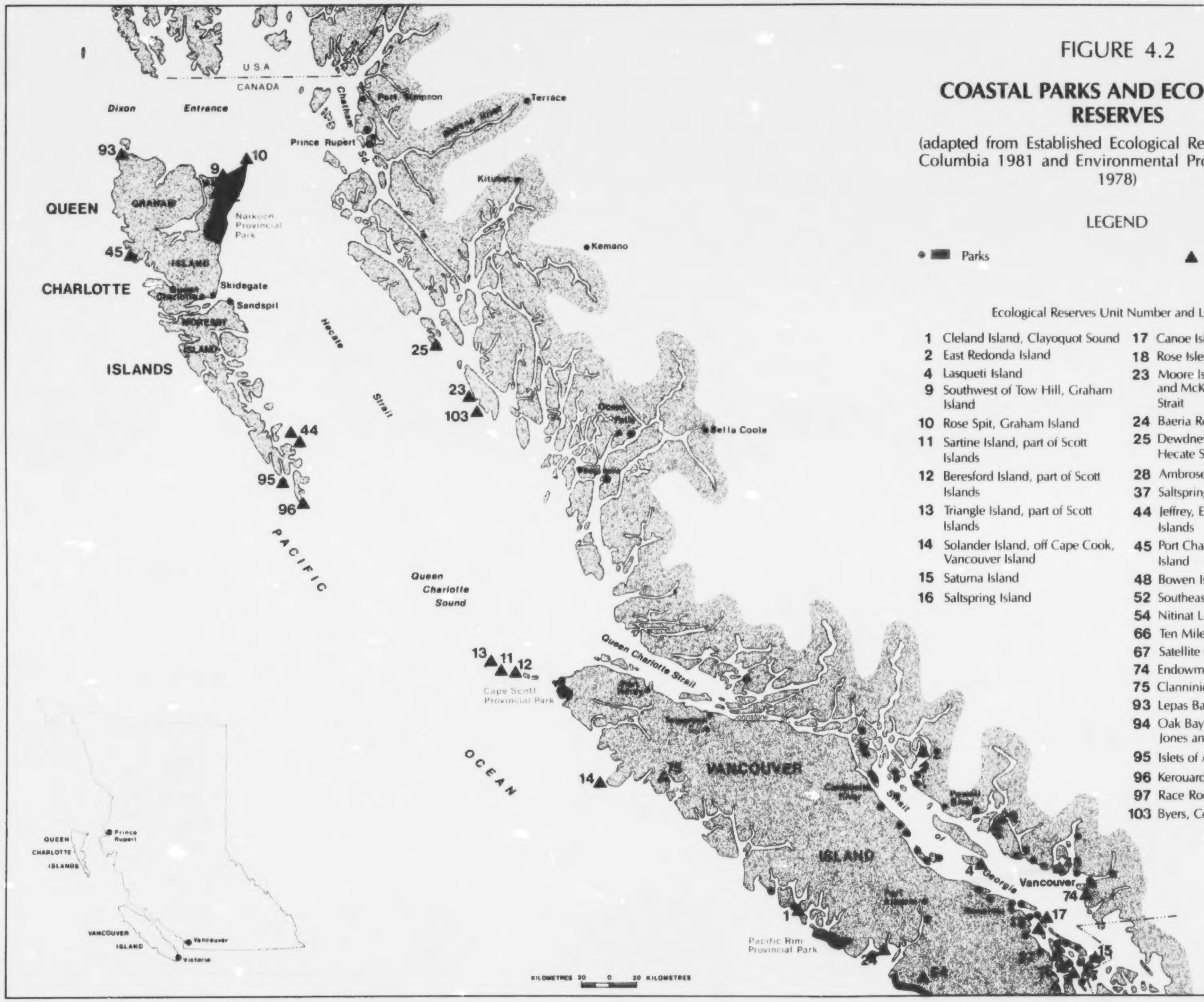
The significance of impacts from hydrocarbon development on present and future recreational opportunities is difficult to assess at this preliminary stage but potential problems can be identified.

Recreational opportunities would be reduced if beaches, coasts and recreational boating areas were polluted by a major spill or by smaller spills and leaks during routine operations. Shellfish gathering and sport fishing would also be vulnerable. Recreational opportunities could be reduced locally as a result of onshore development in areas of some recreational significance. In some cases, pressure on environmental amenities (e.g., hunting pressure, park crowding) may occur due to population influx. However, increases in transient and permanent populations in these areas could also result in localized growth in tourism and recreational facilities.

Recreational areas of particular susceptibility to offshore spills are coastal parks, particularly Pacific Rim National Park and Cape Scott Provincial Park on Vancouver Island; and Naikoon Provincial Park, Anthony Island Provincial Park and Delkatla Wildlife Sanctuary in the Queen Charlotte Islands (Figure 4.2). South Moresby Island in the Queen Charlottes, which has been proposed as a wilderness area for several years, "represents a major portion of a distinct physiographic and as yet unprotected region of B.C." (E.L.U.C. Secretariat, 1979). Although visitor use of the northern coast is not presently high, many areas such as the beaches of Graham Island (Queen Charlotte Islands) and the west coast of Vancouver Island are particularly attractive and visitor use is increasing. Table 4.3 identifies some of the unique recreation opportunities and historic sites in these regions. Both present recreational activities and options for expansion should be considered when planning offshore development.

### 4.5.3 EFFECTS ON LOCAL COMMUNITIES

The rate of population growth determines the severity of impacts on the local community. Population increase depends on the type, location and scale of development. (A typical development pattern is represented by Figure 4.1 in Section 4.2). Residential, commercial and industrial development in any community will cause incremental increases in air and water pollution. A larger community with existing infrastructure and a diversi-


U.S.A.
CANADA
Dixon
Entrance
Chatham Sd.
Port Simpson
Terrace
Prince Rupert
Skeena River
Kitimat
Kemano
93
9
10
QUEEN
GRAHAM
Naikoon Provincial Park
45
ISLAND
CHARLOTTE
Skidegate
Queen Charlotte
Sandspit
MORESBY
ISLAND
ISLANDS
Hecate
Strait
25
23
103
Bella Coola
44
95
96
PACIFIC
Queen
Charlotte
Sound
13
11
12
Cape Scott Provincial Park
Queen Charlotte Strait
OCEAN
14
75
VANCOUVER
ISLAND
Strait of Georgia
4
Vancouver
74
17
1
Pacific Rim Provincial Park
15
54
KILOMETRES 20 0 20 KILOMETRES
QUEEN CHARLOTTE ISLANDS
Prince Rupert
VANCOUVER ISLAND
Vancouver
Victoria

## FIGURE 4.2

## COASTAL PARKS AND ECOLOGICAL RESERVES

(adapted from Established Ecological Reserves in British Columbia 1981 and Environmental Protection Service 1978)

LEGEND

● ▬ Parks ▲ Ecological Reserves

Ecological Reserves Unit Number and Location

| | |
|---|---|
| **1** | Cleland Island, Clayoquot Sound |
| **2** | East Redonda Island |
| **4** | Lasqueti Island |
| **9** | Southwest of Tow Hill, Graham Island |
| **10** | Rose Spit, Graham Island |
| **11** | Sartine Island, part of Scott Islands |
| **12** | Beresford Island, part of Scott Islands |
| **13** | Triangle Island, part of Scott Islands |
| **14** | Solander Island, off Cape Cook, Vancouver Island |
| **15** | Saturna Island |
| **16** | Saltspring Island |
| **17** | Canoe Islets near Valdes Island |
| **18** | Rose Islets, Trincomali Channel |
| **23** | Moore Islands, Whitmore Islands, and McKenney Islands, Hecate Strait |
| **24** | Baeria Rocks, Barkley Sound |
| **25** | Dewdney Island and Glide Islands, Hecate Strait |
| **28** | Ambrose Lake, Sechelt Peninsula |
| **37** | Saltspring Island—Mount Maxwell |
| **44** | Jeffrey, East Copper and Rankine Islands |
| **45** | Port Chanal, west coast of Graham Island |
| **48** | Bowen Island |
| **52** | Southeast of Masset |
| **54** | Nitinat Lake, Vancouver Island |
| **66** | Ten Mile Point, Victoria* |
| **67** | Satellite Channel |
| **74** | Endowment Lands, UBC |
| **75** | Clanninick Creek near Kyuquot |
| **93** | Lepas Bay, Petrel Island |
| **94** | Oak Bay Islets, Alpha, Jemmy Jones and the Chain Islets* |
| **95** | Islets of Anthony Island |
| **96** | Kerouard Islands Reserve |
| **97** | Race Rocks* |
| **103** | Byers, Conroy and Harvey Islands |

* not shown

TABLE 4.3

SPECIAL SITES

| Coastal Section | Number of Archaeological Sites Identified | Designated National Historic Sites | Unique Recreation Opportunities | Beaches (statute miles) |
|---|---|---|---|---|
| Skeena-Queen Charlotte | | | | |
| Islands | 351 | | Naikoon | 100 |
| Mainland | | | | |
| Kitimat-Stikine | 33 | | | |
| Central Coast | | | Rivers Inlet | 3 |
| Mt. Waddington | | | | |
| Mainland (& Island) | | | | |
| East Island | | | | |
| West Island | | | Cape Scott Trail | 10 |
| Cowichan Valley | | | | |
| East Island | 125 | | | |
| West Island | | | West Coast Trail | |
| Alberni-Clayoquot | 101 | 2 | West Coast Trail<br>Long Beach | 8 |

(Fisheries and Environment, 1978b)

fied economic base will generally cope more effectively with onshore oil and gas development than a smaller town with limited a labour pool, services and housing.

Environmental impacts of community growth are inter-related with social and economic impacts. Onshore oil and gas facilities are heavily industrial in nature and would need to be assessed to determine their consistency with short and long-term community goals. In British Columbia, these goals are found in regional plans which also include land and water use policies. Each community may have an Official Community Plan or Official Settlement Plan which outlines more detailed objectives and policies. Zoning by-laws are the means by which the community controls local land and water use.

Plate 18: Possible impacts of offshore hydrocarbon development on heritage resources in British Columbia will need to be assessed.

*(Photo by B. Wolferstan)*

Proposed new land use planning legislation for British Columbia would change the existing planning framework but would require the preparation of planning "statements" which would perform a similar function to existing plans.

Offshore and related onshore development in British Columbia should conform to the resource management objectives outlined in the following plans (and others which are completed over time):

a. Crown Land Plan: Graham Island Land Plan (Ministry of Lands, Parks and Housing)

b. Regional Plans: Mt. Waddington, Port Clements, Prince Rupert, Queen Charlotte City, Port Edward, Bella Bella/Bella Coola, Port Hardy, Port McNeil (in preparation), Port Alberni

c. Official Settlement Plans: Malcolm Island, Coal Harbour, Bamfield (in preparation), Hide Creek, Quatsino, Cherry Creek, Sprout Lake, Beaver Creek, Beaufort

Case studies in the United states found that many of the decisions affecting onshore development were made at senior levels of government while local governments were left to cope with onshore impacts. Many small communities involved with the servicing of offshore fields suffered the following kinds of problems:

- a lack of involvement in siting and planning of development
- a lack of resources or staff to adequately predict or plan for impacts
- a lack of adequate capital necessary to fund new services and facilities
- inadequate local development regulations (local zoning and by-law systems are not usually geared to rapid or temporary growth)
- inexperience in administering controls
  (adapted from Office of State Planning, 1976)

It was noted that inadequate local control of development due to these factors had decreased potential local benefits.

British Columbia has numerous small coastal communities where development impacts could be substantial. Involvement of local and regional governments in onshore planning and management will help to maximize the benefits and minimize the impacts of offshore development in these areas. Examples of successful approaches are found in Scotland and Alaska. Case studies of these areas emphasize the importance of strong local involvement and comprehensive early planning in effectively dealing with onshore impacts (Nelson and Jessen, 1981; Kramer et al., 1978; Gilbert, 1982).

Also emphasized in the literature is the importance of involving the general public in the assessment and planning of offshore and related onshore development. Potential participants include local government officials, local business people, union officials, labour organizations, fishermen, onshore resource users, and environmental groups. Public involvement will further ensure that the proposed resource development is consistent with local and regional goals and will facilitate maximum local benefits. A well-designed public information program starting in the pre-exploration phase should be part of this involvement process.

### 4.5.4 ARCHAEOLOGICAL SITES

Although archaeological investigation for this area is in its initial inventory stage, numerous significant heritage sites have been found. Approximately half of British Columbia's 14,000 documented sites are situated along the coast. Some of these sites may be susceptible to damage from oil pollution or from the construction of onshore facilities. Underwater sites would be most susceptible to oil spill damage. Only eleven of these sites have been excavated along the north-west coast, but archaeologists indicate a high probability of finding additional sites (Trans-Mountain, 1980a).

While the total number of identified coastal archaeological sites is listed for each regional district in Table 4.3, these numbers are not precise due to the following factors:

a. inventory in British Columbia is still in progress
b. additional sites are often discovered in the process of working on a known site, thus numbers may be higher in areas already receiving attention
c. there are potentially thousands of undiscovered sites in bays and at river mouths along the coast
c. qualitative comparison of coastal sites is difficult (Fisheries and Environment, 1978b)

Archaeological sites have the potential to yield information pertinent to the reconstruction of human history along the British Columbia coast.

Siting of onshore facilities away from archaeological sites and spill contingency plans which allow for containment of oil away from sensitive areas should alleviate most concerns.

### 4.5.5 ECOLOGICAL RESERVES

Ecological reserves, which are established by the British Columbia Ministry of Lands, Parks and Housing are set aside because they possess some unique quality or because they represent a particular ecological community. Figure 4.2 shows the coastal ecological reserves in the area of reference. The reserves are primarily for scientific purposes with only limited public use permitted. Coastal reserves could suffer temporary or irreversible damage from major or routine oil leaks and spills. Of particular note is Anthony Island (Figure 4.2 - #95), which has recently been declared by the United Nations as a World Heritage Site and which could be susceptible to oil spill damage. Other coastal sites such as Windy Bay are being considered as ecological reserves. As more information on this region is gathered, other sites will likely be proposed for preservation (Bristol Foster, pers. comm., 1981).

### 4.5.6 NAVIGATION

Marine congestion could result from increased traffic in navigable nearshore waterways. The number of deep-sea ship movements in and out of Prince Rupert harbour has increased from 7/month in 1976 to 45/month in 1981 (G.W. Thompson, pers. comm., 1981). There is not as much concern regarding congestion of navigable northern waters as there is in southern waters, where there are more recreational boats. There is some conflict in the Prince Rupert area where fishermen continue to set nets in traditional fishing areas now being used as shipping routes. Since full development of offshore activities will not likely occur for 5-10 years, navigation pressures will likely have increased by then. Potential problems can be reduced through a vessel traffic management system.

### 4.5.7 FOREST PRODUCTS

Most of the logs harvested in the Queen Charlotte Islands are moved to mainland conversion mills through Hecate Strait, an area of significant interest for hydrocarbon exploration. Some oiling of logs in booming and sorting areas could occur in the case of a large spill or from small leaks and spills in harbour areas. Oiled logs can be used but their quality and value may be reduced. Efforts to contain oil slicks away from log-handling areas would eliminate the risk of oiling.

## 4.6 SUMMARY

A variety of onshore facilities are developed in association with offshore hydrocarbon exploration and production. This onshore development includes:

i) Facilities directly related to offshore acivity (e.g., service base, oil and gas transportation system)
ii) Facilities ancillary to servicing activity (e.g., drilling fluid supplier, pipe coating yard)
iii) Facilities associated with product processing (e.g., gas processing plant, refinery)
iv) Development induced by the oil and gas related facilities (e.g., increased housing and roads)

If offshore hydrocarbon exploration and development is permitted in British Columbia, resulting onshore environmental impacts could be significant. However, it is difficult to assess the consequences of onshore development since impacts would depend on the location, type, design, scale and timing of facilities as well as the biophysical characteristics of the coastal sites used. British Columbia can make use of available information on offshore hydrocarbon developments in Canada and elsewhere (i.e., Alaska, Continental U.S.A., Scotland, Norway) to identify and cope with potential impacts.

It is not yet possible to identify specifically where onshore development would take place in this province. However, since there is a commitment by the Province not to allow exploration in the Straits of Georgia and Juan de Fuca nor in Johnstone Strait, onshore servicing areas would likely be located outside of these water bodies at an existing port.

The activities and impacts associated with the construction and operation of onshore facilities are similar to those associated with other coastal industries and ports. The preparation of flat, well-drained coastal sites and the development of berthing and servicing facilities for supply and service boats may involve dredging, filling and wharf construction, each of which can result in the elimination and degradation of aquatic habitat. Vegetation removal, soil disturbance and paving, also associated with site preparation, may remove or disturb both aquatic and terrestrial habitats. Air emissions, waste water discharges and disposal of solid wastes associated with onshore development can contribute to air, water and land pollution and degrade wildlife habitat. Facilities such as a service base and processing plant will generate noise and light disturbance on a 24-hour basis. While direct impacts may not be significant, noise and light can be a "nuisance" factor for animals (especially birds) and nearby residential areas.

In addition to these impacts, the consequences of onshore development for other coastal resource uses such as fishing, recreation and tourism are also of concern in British Columbia. Based on examples from elsewhere in the world, onshore planning and regulatory processes can mitigate the grosser impacts of onshore development if properly designed and administered. A strong local government role and involvement of the public in project assessment and planning assist in minimizing the negative impacts of development.

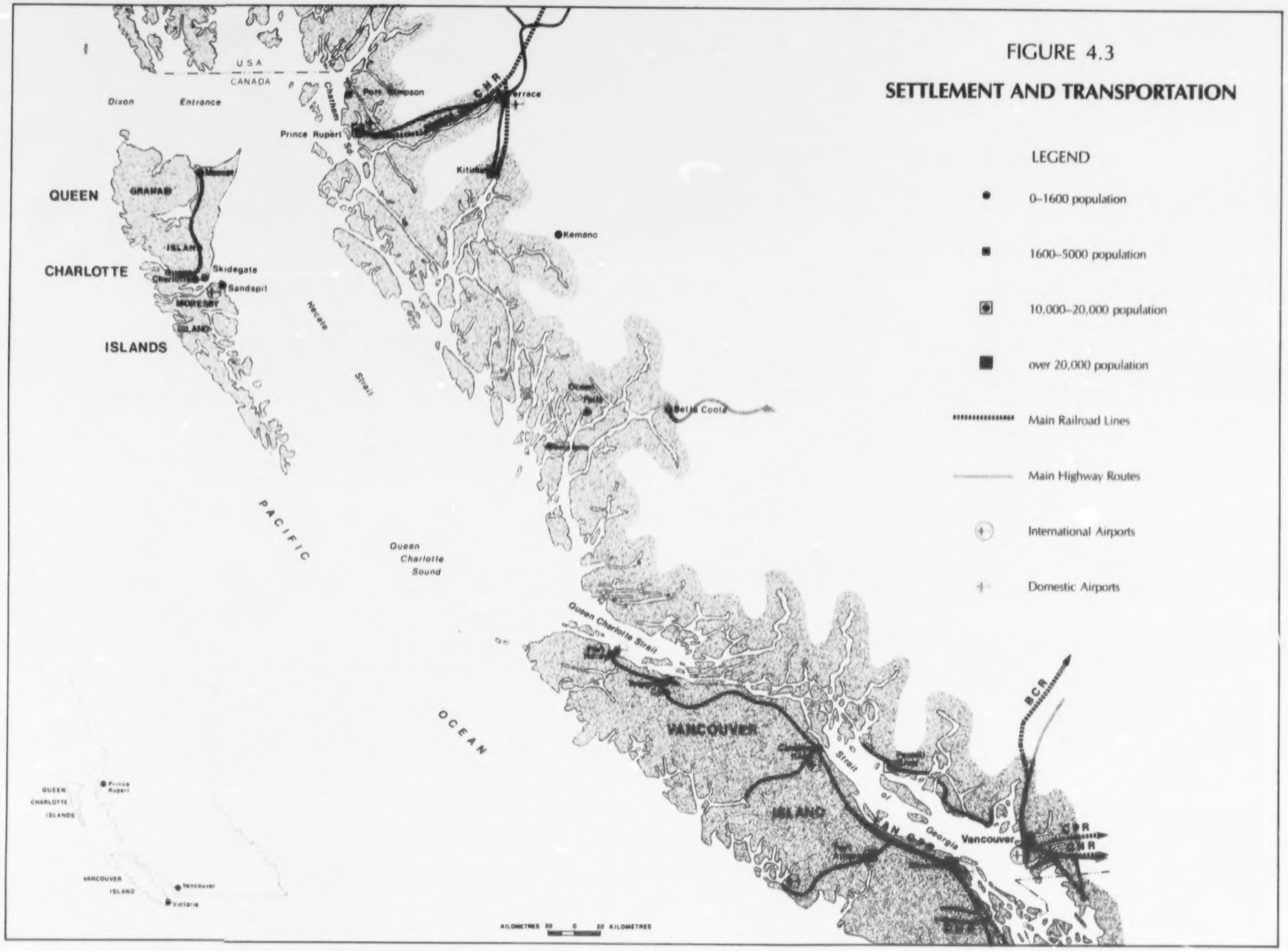


FIGURE 4.3

SETTLEMENT AND TRANSPORTATION

LEGEND
● 0–1600 population
■ 1600–5000 population
▣ 10,000–20,000 population
■ over 20,000 population
Main Railroad Lines
Main Highway Routes
International Airports
Domestic Airports
USA
CANADA
Dixon
Entrance
Chatham Sound
Port Simpson
Prince Rupert
CNR
Terrace
Kitimat
Kemano
QUEEN
CHARLOTTE
ISLANDS
GRAHAM
ISLAND
MORESBY
ISLAND
Skidegate
Sandspit
Hecate
Strait
Bella Coola
PACIFIC
OCEAN
Queen
Charlotte
Sound
Queen Charlotte Strait
VANCOUVER
ISLAND
Strait
of
Georgia
Vancouver
BCR
CPR
CNR
QUEEN
CHARLOTTE
ISLANDS
Prince
Rupert
VANCOUVER
ISLAND
Vancouver
Victoria
KILOMETRES 20 0 20 KILOMETRES

# CHAPTER 5

# OFFSHORE RISKS AND CONTINGENCY PLANNING

Bill Wolferstan
Jim Slater

# CHAPTER 5—OFFSHORE RISKS AND CONTINGENCY PLANNING

## 5.1 INTRODUCTION

The purpose of this chapter is to describe and assess the major risks associated with offshore exploration, development and production. This has been done by analyzing the major types of accidents and hazardous operations which result in oil pollution. Oil spills can occur either as unexpected and sometimes catastrophic accidents or as the result of normal operations ("chronic" pollution). The relative risks (probabilities of occurrence) of these incidents in the different phases of offshore activity, their causes and the potential for risk reduction are outlined in the following sections. The chapter concludes with an outline of the factors which need to be considered in developing an effective contingency plan to deal with the risks of an oil spill from offshore activities.

## 5.2 ACCIDENTS AND OPERATIONAL HAZARDS

There are several types of accidental or operational hazards that can lead to significant pollution or disturbance to British Columbia resources. These can range from the sometimes spectacular blowout, vessel accident or storage tank rupture to pollution from normal operations such as pipeline or valve leaks. Statistics indicate that the relative risks of a major oil spill occurring during the exploratory phase of oil development are very low and that spill likelihood increases only slightly during the development phase. The probability of an oil spill during the production and transportation phase is, in comparison, relatively high (State of Alaska, 1981).

### 5.2.1 BLOWOUT RISKS

A blowout is an uncontrolled flow (or "kick") of oil or gas and other fluids (Baker, 1978). Blowouts are caused when pressures within the formation overcome the counterpressures of drilling fluids and safety devices designed to prevent blowouts. Although blowouts are often dramatic events, their contribution to marine pollution on a global scale is minimal. Table 3.8 (Chapter 3) indicates that approximately 1% of all petroleum which enters the ocean comes from offshore production activities. In the USA, offshore production facilities produced 12.3% of the total oil pollution incidents in 1979, but only 0.5% of the total volume of oil spilled (Harrald et al., 1977). More recent studies have indicated that offshore drilling now accounts for up to 4% of the oil introduced into the oceans from all sources (OECD, 1977; from McPhee, 1982).

Offshore blowouts, despite their low probability of occurrence, can be locally damaging, especially where there is a possibility of a blowout remaining uncontrolled for a long period of time. This will happen if relief rigs are unavailable or weather conditions prevent corrective action from being taken. It is possible that during the exploration phase in British Columbia only one drilling rig would be operating on the west coast, and the nearest rig for drilling a relief well might be thousands of miles away in Alaska or the southwest Pacific.

A blowout of the magnitude of the 1979 Gulf of Mexico spill (430,000 metric tons) could impact a large part of the northern British Columbia coast if it occurred in Queen Charlotte Sound. A blowout similar in size to the Santa Barbara blowout (10,000 metric tons) could affect most of the east coast of Graham Island. In the entire history of offshore drilling operations there have only been six blowouts resulting in large spillages of oil.

Bercha and Associates (1978) have summarized the probabilities of blowouts according to various sources (see Table 5.1). This table indicates that while offshore blowouts have a greater probability of occurring than land blowouts, oil blowouts are less frequent than gas blowouts.

Baker (1978) has indicated that about one in every 100 wells in Alaska and one in every 200 wells in the North Sea is a blowout but notes that blowout estimates and their causes must be treated with caution until

# TABLE 5.1

## STATISTICAL DATA ON THE PROBABILITY OF BLOWOUTS

(Source: Bercha and Associates Ltd., 1978; from Petrocan, 1982)

| PROBABILITY OF EVENT/WELL | | | | |
|---|---|---|---|---|
| ITEM | BLOWOUT ON LAND | BLOWOUT OFFSHORE | OIL BLOWOUT OFFSHORE | REMARKS |
| Kash *et al.*, 1973 | $0.38 \times 10^{-3}$ | $2.3 \times 10^{-3}$ | $3.0 \times 10^{-4}$ | Production wells mostly. Offshore are all fixed platforms. |
| Goodwin, 1972 | $0.4 \times 10^{-3}$ | $2.3 \times 10^{-3}$ | $2.7 \times 10^{-4}$ | World production and exploration; mobile rigs. |
| Goodwin, 1972 | - | $5.2 \times 10^{-3}$ | $6.2 \times 10^{-4}$ | North Sea - production and exploration. |
| Greene and MacKay, 1976 | - | $6.0 \times 10^{-3}$ | - | Exploratory. |
| MacKay, 1976 | - | $2.5 \times 10^{-3}$ | - | Exploratory. |
| Milne and Smiley, 1977 | - | $1.0 \times 10^{-3}$ | $1.0 \times 10^{-4}$ | Milne and Smiley quote probability of oil or oil plus gas blowouts within range shown. |
| Snider *et al.*, 1976 | - | $4.7 \times 10^{-3}$ | $3.7 \times 10^{-4}$ | All blowouts occurred for self-elevating or semi-submersible units. None for drillships which constituted 12% of population. Mostly production drilling. One-twelfth of blowouts have oil. |
| Average | $0.39 \times 10^{-3}$ | $3.4 \times 10^{-3}$ | $3.3 \times 10^{-4}$ | Note that oil blowout means blowout with which oil is associated; hence, generally a small oil blowout. |
| Bercha, 1978 | $0.46 \times 10^{-3}$ | $2.4 \times 10^{-3}$ | $3.0 \times 10^{-4}$ | Information averaged from Table 6.2 of F.G. Bercha and Associates Ltd. (1978) |

accident reporting and analysis is improved. Bercha also notes that blowout documentation "amounts to little more than accident counts." No correlations are made between the statistics and environmental conditions, oil volumes, and exploratory or production drilling frequency. Some work has been done on the causes of blowouts (Kennedy, 1971). It is difficult to quantify these probabilities other than to say that the causes appeared to be predominantly operator error.

Although most sources note that there is a greater chance of blowouts in production than exploration wells, (possibly due to overconfidence), it has been noted that where geological formations are uncertain, exploratory wells also lead to blowouts (McPhee, 1982).

In a study of 19 production well blowouts, it was found that 10 (53%) occurred while bringing the drill string out of the hole. The cause was attributed to improper training, inability to accurately measure mud pit volume, late detection of flow and the use of ineffective or improperly installed blowout preventers (Kennedy, 1971; from FENCO, 1979).

The Royal Commission on Environmental Pollution (U.K.) recently published a report entitled "Oil Pollution of the Sea". The report states that a blowout in the North Sea could spill 6 000 to 13 000 metric tons of oil per day, but since the U.K. began its North Sea oil explorations only 4 small blowouts have occurred. According to estimates provided by the U.S. Department of Environment (DOE), one blowout is likely to occur in the next 2 to 3 years, and there is a 2 - 3% probability that the blowout will spill more than 10 000 metric tons of oil before it is controlled. The U.K. Commission concluded, however, that the principal cause for concern is "that blowouts at oil production sites within striking distance of the shore could have very serious consequences." (Oil Spill Intelligence Report, 19 March, 1982).

Baker (1978) has noted that technological developments could contribute to the early identification and control of blowouts, although industry tends to identify human error as the main problem. It has been suggested that the risk of blowouts can be reduced by 1) proper and complete training of drilling and well servicing crews, 2) ensuring that operating crews have experience suitable for the conditions which they may encounter, and 3) design, testing, installation and proper use of blowout prevention and safety equipment (adapted from Fenco, 1979).

Operational hazards such as weather, seismic activity, thermogenic gas charging and biogenic gas cratering risks are covered in Chapter 2, Sections 2.2.2 to 2.2.3 and 2.2.7 to 2.2.9.

### 5.2.2 FIRES AND EXPLOSION RISKS

During the history of production on the U.S. outer continental shelf, there have been many fires of various sizes. Most have involved gas wells and have been extinguished before serious damage and pollution occurred. Of 81 recorded explosions and fires only 4 have resulted in pollution of the sea by oil. The total volume spilled is estimated at 84,050 bbl. This volume is from a sample of producing systems in which 2.9 billion bbl of oil and condensate were produced - a spillage rate of 0.003%. (Department of Interior, 1976; from Fenco, 1979).

### 5.2.3 VESSEL RISKS

All phases of offshore development which involve vessels for product handling, transport or well servicing involve a high degree of risk. Table 3.8 indicates that up to 35% of all petroleum entering the oceans comes from tankers or other vessels. The Fenco (1979) study concluded that the greatest risks of oil pollution occur during product transfer and transportation. The impacts and operation of service vessels and tankers have also been discussed earlier in Sections 3.3.1.1 and 3.3.5.2. This section deals primarily with the risks of a major tanker casualty resulting from product movement from offshore production.

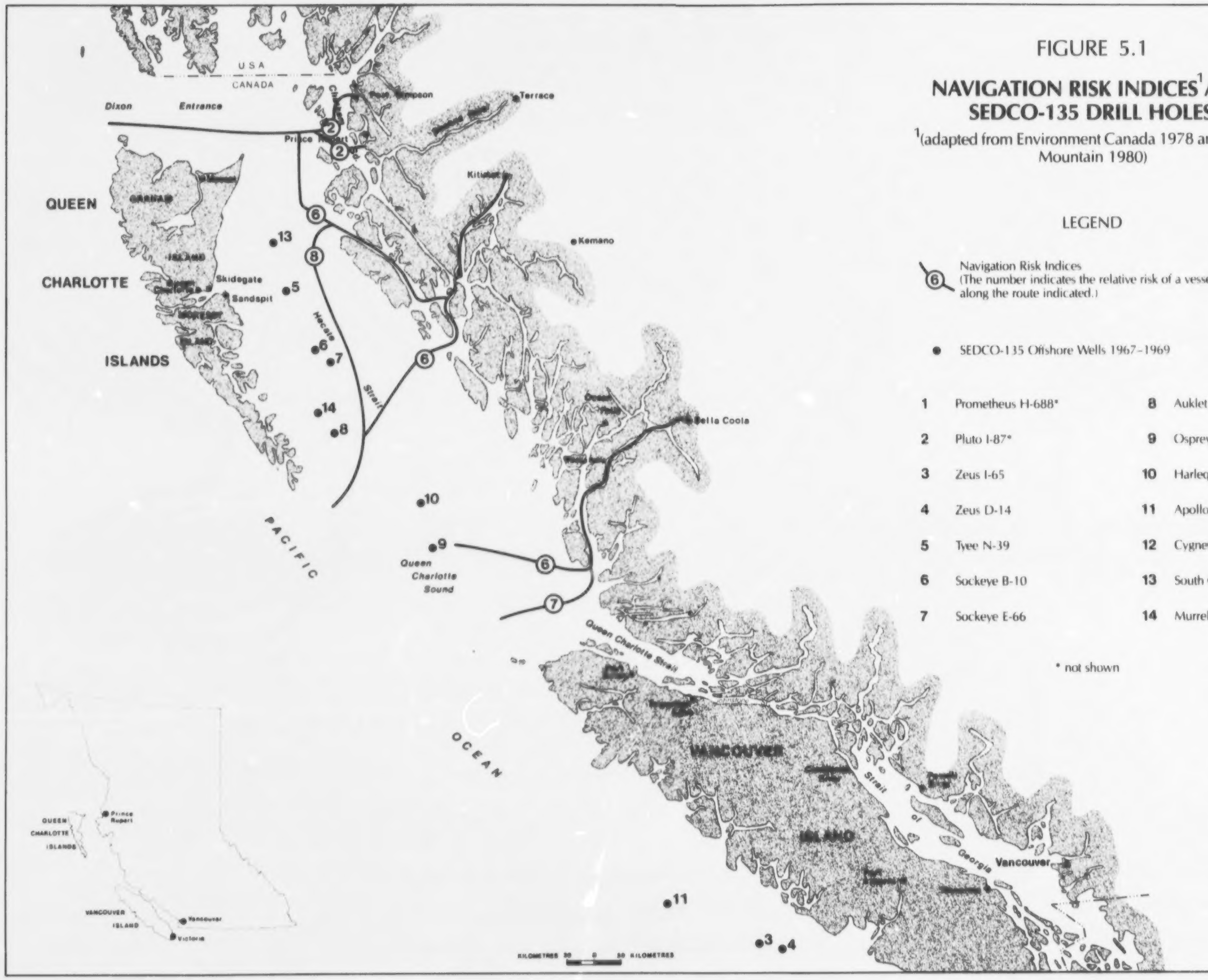
The potential routes for tankers or barges from possible production areas to north coast ports are depicted on Figure 5.1 with a relative risk indicator for each route (adapted from Fisheries and Environment Canada, 1978b). This relative risk is based on a navigational risk index which incorporates the following indicators: wind, visibility, water depths, passage widths, course changes and shipping density.

Collisions with other vessels will be less likely in the more isolated areas away from major shipping lines, but future increases in traffic to Prince Rupert could be of concern unless effective avoidance systems or full radar coverage (as part of a comprehensive Vessel Traffic Management (VTM) system) are made mandatory. It has been demonstrated that a fully operational VTM System can reduce casualties by up to 60% (U.S. Coast Guard, 1978).

If a North Coast port site such as Kitimat were used to either tranship, or land oil from offshore production, the expected number of spills from tanker casualties would more than double from the existing risk (of tanker traffic into Puget Sound). Assuming a throughput of 800,000 bbl/day one could expect 3.17 spills, averaging 5000 barrel size, every ten years (ELUCS, 1978).

As Table 3.8 indicates however, the global input of petroleum into the ocean from tanker accidents is 3% while intentional discharges from both LOT (Load on Top) and non-LOT tankers is 18%. This risk (intentional discharge of ballast water) will only concern British Columbia if a decision is made to use tankers to either export oil or bring it ashore from production areas, rather than pipe it ashore. It has been estimated that 0.016% of all the oil produced by offshore production is spilled in tanker accidents as the oil is transported to market (State of Alaska, 1981).

Tank barges have also been shown to be major sources of oil pollution. In 1975, 7.5% of all oil pollution incidents in the U.S.A. involved tank barges spilling 82,546 barrels of oil. This was 24% of the total oil spilled in the U.S. that year (Harrald et al., 1977). Other potential con-


U.S.A.
CANADA
Dixon Entrance
Port Simpson
Terrace
Prince Rupert
Kitimat
Kemano
QUEEN CHARLOTTE ISLANDS
Skidegate
Sandspit
Hecate Strait
Bella Coola
PACIFIC OCEAN
Queen Charlotte Sound
Queen Charlotte Strait
VANCOUVER ISLAND
Strait of Georgia
Vancouver
Victoria
Prince Rupert
2
6
8
6
6
7
13
5
6
7
14
8
10
9
11
3
4
KILOMETRES 30 0 30 KILOMETRES

## FIGURE 5.1

## NAVIGATION RISK INDICES[1] AND SEDCO-135 DRILL HOLES

[1](adapted from Environment Canada 1978 and Trans Mountain 1980)

LEGEND

⑥ Navigation Risk Indices
(The number indicates the relative risk of a vessel casualty along the route indicated.)

● SEDCO-135 Offshore Wells 1967-1969

| | | | |
|---|---|---|---|
| 1 | Prometheus H-688* | 8 | Auklet G-41 |
| 2 | Pluto I-87* | 9 | Osprey D-36 |
| 3 | Zeus I-65 | 10 | Harlequin D-86 |
| 4 | Zeus D-14 | 11 | Apollo J-14 |
| 5 | Tyee N-39 | 12 | Cygnet J-100* |
| 6 | Sockeye B-10 | 13 | South Coho I-74 |
| 7 | Sockeye E-66 | 14 | Murrelet L-15 |

* not shown

tributors to oil pollution are drillships and other floating platforms, which are susceptible to sinking during drilling operations. Very high sea states, rogue waves (up to 30 metres high) and extreme wind conditions (average 40 km/hr more than 30% of the time) are present on the west coast (see Sections 2.2.2 and 2.2.3).

## 5.3 RISK OF SPILLS

In addition to the risks of major accidental spills from blowouts, explosions or vessel casualties, smaller spills such as fuel leaks from supply vessels, lubricants spilled off a drilling platform or products released from storage tanks can occur and go unreported.

Some indication of the likelihood of spills and their causes may be gained from foreign operations. Oil spills greater than one barrel on the Gulf of Mexico Outer Continental Shelf are shown in Table 5.2 for the period 1971-75. During these five years the total oil production in the area was 1.811 billion barrels. This shows that a total of 50,000 barrels was spilled, a spillage rate of 0.003%. While it is very difficult to extrapolate to Canadian west coast conditions, unless there are significant changes in reducing human error and mechanical failures, this rate of spillage from "normal" operations is not expected to decrease (after Fenco, 1979).

At least 180 oil spills occurred in Cook Inlet, Alaska from 1966 to 1972. The volumes of oil spilled during these incidents varied from less than a barrel to an estimated 15,000-17,000 barrels. An accurate average spill volume cannot be calculated because many of these spills were not reported. Since 1972 the recording of spills has greatly improved and from 1973 to mid 1980 there have been approximately 233 spill incidents totalling less than 800 barrels (State of Alaska, 1981).

The Cook Inlet area is geologically similar to the British Columbia offshore area, and the average expectation of the hydrocarbon potential of the British Columbia offshore area (9 trillion cubic feet of gas and 250

## TABLE 5.2
## OIL SPILLS ON THE GULF OF MEXICO OUTER CONTINENTIAL SHELF (1971-75)

| CAUSES | SPILLS GREATER THAN 50 BARRELS, 1971-75 | | | | SPILLS OF 1-50 BARRELS, 1971-75 | | | |
|---|---|---|---|---|---|---|---|---|
| | # of spills | % of total spills | Spill vol. (bbls) | % of total volume | # of spills | % of total spills | Spill vol. (bbls) | % of total volume |
| Production platform equipment malfunctions or misuse ......... | 6 | 30.3 | 10925 | 23.6 | 536 | 61.5 | 2286 | 58.7 |
| Pipeline pump failures, leaks and breaks ..................... | 7 | 35.0 | 27396 | 59.2 | 232 | 26.6 | 1106 | 28.4 |
| Drilling operations and work-over mishaps .................. | 0 | 0 | 0 | 0 | 20 | 2.3 | 64 | 1.6 |
| Barge spills (leak or oil transfer ...................... | 2 | 10.0 | 7100 | 15.4 | - | - | - | - |
| Workboat spills during unloading of diesel fuel or collision .... | 3 | 15.0 | 506 | 1.1 | - | - | - | - |
| Miscellaneous - equipment failures and employee errors ............ | 2 | 10.0 | 320 | 0.7 | 84 | 9.6 | 440 | 11.3 |
| TOTAL | 20 | 100.0 | 46247 | 100.0 | 872 | 100.0 | 3896 | 100.0 |

(after Dept. of the Interior 1979, from FENCO, 1979)

million barrels of oil) is similar to the combined hydrocarbon equivalents already found in Cook Inlet (Haimila and Procter, 1981).

On the U.S.O.C.S. (United States Outer Continental Shelf) from 1964-1979 there were 9 spills of over 1000 barrels, 4 of which were greater than 10,000 barrels. During this period U.S.O.C.S. production was 4,386,000,000 barrels.

Projections of spill rates per billion barrels of oil produced in the Norton Sound area of Alaska are outlined in Table 5.3.

TABLE 5.3

EXPECTED NUMBER OF SPILLS PER $10^9$ BARRELS OF OIL PRODUCED

| Source | Spill Size | |
|---|---|---|
| | >1,000 bbl | >10,000 bbl |
| Platforms | 2.05 | 0.91 |
| Pipelines | 1.82 | 0.46 |
| Tankers | 3.87 | 2.32 |
| TOTAL | 7.74 | 3.69 |

More recent estimates of the probability of oil spills have been published in the draft EIS (Environmental Impact Statement) for the Diapir Field in the Beaufort Sea off Alaska. Using 1979 and 1980 statistics from OCS (Outer Continental Shelf) activities, the report predicts 9.2 spills of over 1,000 gallons and 3.3 spills of over 10,000 gallons (based on statistics for the Gulf of Mexico and the California coast); plus 5.6 spills of over 1,000 gallons and 1.7 spills of over 10,000 gallons (based on statistics for Prudhoe Bay production) (Oil Spill Intelligence Report, 15 Jan., 1982). Estimates of spill probability for the British Columbia offshore area are included in Section 5.7.

## 5.4 OTHER POLLUTION RISKS

In addition to the risks of offshore oil spills, there are other pollution risks which are covered in Chapter 3 (Offshore Biological Environment) and Chapter 4 (Onshore Environmental Impacts). These risks include air emissions, litter and noise (Section 3.3.1), sedimentation (Section 3.3.4.1) and the discharge of drilling fluids, formation cuttings, process waters and sewage (Sections 3.3.3.1 and 3.3.5.3).

## 5.5 CAUSES OF ACCIDENTS

### 5.5.1 NATURAL HAZARDS

Natural hazards, such as severe weather and turbulent sea states, are seldom in themselves the direct cause of blowouts or tanker casualties, although they are often contributing factors. Bercha (1978) estimates that 7% of blowouts in the Beaufort Sea are caused by unexpected natural hazards. Storms can disrupt standard operating procedures on drilling platforms. If severe weather conditions arrive unexpectedly there may be little time for proper safety procedures to be followed in suspending drilling operations, checking blowout prevention pressure or shifting ballast, as was the case with the Ocean Ranger sinking (Feb., 1982). Thobe (1974) reports that storms were involved in 46 of 95 rig mishaps between 1955 and 1974.

Seismic activity is seen to be a major natural hazard, and a potentially greater risk to drilling platforms, pipelines and storage tanks than other natural hazards such as high winds and waves (Yorath, pers. comm. 1982). The possibility of seismic activity and other geologic hazards such as faulting, thermogenic or biogenic gas reservoirs, current scouring, and slumping and liquefaction of sediment (discussed in Chapter 2) need to be thoroughly assessed in a comprehensive risk analysis prior to offshore exploration activity. These hazards need to be studied in enough detail over long lead times in order to provide data for the design and engineering of offshore structures and to assist in contingency planning.

### 5.5.2 MECHANICAL BREAKDOWN

For worldwide offshore operations in general, poor equipment design and engineering and lack of quality control are seen to be important causes of mechanical breakdowns, corrosion, and structural and fatigue failures. Such failures can affect drilling platforms, pipelines, storage and processing equipment, transfer lines, and valves and connections. Bercha (1978) estimates that 17% of blowouts in the Beaufort Sea will be caused by equipment failure and 8% will be caused by inadequate engineering. Fenco (1979) notes that "Corrosive failures occur in separation and processing equipment, especially where corrosive fluids or gases are produced as byproducts. The flow of high pressure gases and condensates carrying sand can be extremely erosive, especially in choke lines, and if not accounted for can lead to blowouts and discharges." Production platforms, subsea equipment, pipelines and tankers may also be affected by seawater corrosion for periods of up to 20 years before replacement. Protective coating and the use of anodes have not been completely successful in combating this problem. Machemehl (1979) finds corrosion to be the largest single cause of pipeline failures in the Gulf of Mexico.

Tankers carrying high sulphur crude oils have been corroded to the point of weakening the internal integrity of the vessel with resultant structural failure (Mostert, 1974).

Fingas _et_ _al_. (1978) notes that equipment failure or malfunction is responsible for up to 25% of all oil spills.

Virtually all offshore facilities can be affected by a combination of fatigue, corrosion due to salt water or other fluids or gases and structural stress. Any combination of these can severely weaken the facility, and extreme weather conditions may bring about failure. These problems can be avoided or reduced by proper design and manufacture, regular maintenance and inspection and through improved forecasting of weather conditions and other natural hazards.

### 5.5.3 HUMAN ERROR

Human error includes the failure to apply proper procedures or the failure to react quickly enough. Bercha (1978) feels that both types of error are more probable during stressful conditions such as bad weather or when well flow occurs. Bercha calculated that the probabilities of human error can vary between one in ten and one in one thousand and result from lack of supervision, experience or training. Baker (1978) has also noted that there are serious deficiencies in enforcement of rigorous safety and training standards.

Several sources have estimated that 75% of all spills are directly or indirectly attributable to human error (Fingas et al., 1978). Robbins (1977) attributes 85% of all vessel casualties to human error.

Methods suggested by Baker (1978) for reducing human error include incentives for candid accident/error reporting by industry, and for an improved training system to upgrade the manpower base, plus rigorous operating procedures.

## 5.6 CONTINGENCY PLANS

Sections 5.6 to 5.10 present some of the factors that need to be considered in developing an effective contingency plan. The aim of contingency planning is to minimize damage from oil spills when they occur. Table 5.4 outlines the steps necessary to determine where spill countermeasure resources are best deployed (adapted from East-West Centre, 1982).

## 5.7 SPILL PROBABILITY

Risk analysis studies of the probability of oil spills should provide estimates of the size and frequency of incidents for each phase of offshore activity. These estimates will be helpful in determining what countermeasures are necessary for each spill scenario. However, it will be important to consider that historical statistics will not reflect recent risk reducing measures such as improvements in safety regulations and accident prevention technology. For this reason, risk analyses must be flexible and dynamic enough to incorporate new data as it is acquired, and to be useful in anticipating the types, frequencies, locations, durations and discharge rates of any spills which might occur.

TABLE 5.4

THE CONTINGENCY PLANNING PROCESS

| STEP | INFORMATION NEEDED |
|---|---|
| 1. SPILL PROBABILITY (Section 5.7)<br>Determine range of estimates for spill occurrence and magnitude | •dynamic risk analysis to incorporate new statistics as acquired<br>•forecasting of physical parameters |
| 2. SPILL DISTRIBUTION (Section 5.8)<br>Determine when and where spills could occur that might threaten vulnerable resources | •physical parameters<br>•spill trajectories<br>•resource location and size estimates |
| 3. RESOURCES AT RISK (Section 5.9)<br>Determine relative vulnerability of environmental resources to oil spill impact | •biological resources<br>•habitat types must be priorized on seasonal, geographical basis<br>•socio-economic resources |
| 4. OIL SPILL COUNTERMEASURES (Section 5.10)<br>Determine what countermeasures are feasible and appropriate for various spill scenarios | •values of resources<br>•availability and costs of countermeasures<br>•produce contingency plan |

Oil spill risk analyses by the U.S. Department of Interior have used volume of oil produced as the major variable for estimating spill occurrence and magnitude. Their estimates assume that local geology, geography and weather conditions will have little influence on spill probability, but that the mode of transport is a major factor. If tankers are used, there will likely be one spill over 1000 barrels in size for every 175 million barrels of oil produced. If pipelines are used, there will likely be one spill over

1000 barrels for every 240 million barrels of oil produced (U.S. Department of Interior, 1980).

Extrapolating these estimates to the British Columbia offshore area will give the spill probability estimates contained in Table 5.5.

## 5.8 SPILL DISTRIBUTION

The final distribution of spilled oil following an offshore blowout, tanker casualty or pipeline rupture is difficult to predict. To help solve this question the determination of a particular oil's rate of weathering and spreading, along with its toxicity, are critical factors to know and understand.

TABLE 5.5

SPILL PROBABILITY ESTIMATES

| OIL PRODUCED | TRANSPORTATION MODE | TOTAL NUMBER OF SPILLS GREATER THAN 1000 BARRELS EXPECTED |
|---|---|---|
| Average expectation* (50% probability) 250 million barrels | Tanker<br>Pipeline | 1.43<br>1.04 |
| Ultimate Expectation* (0% probability) 5000 million barrels | Tanker<br>Pipeline | 28.6<br>20.8 |

* Estimates of oil existence in British Columbia offshore area and percent probability of oil being found (from Haimila and Procter, 1981).

### 5.8.1 TYPES OF OIL

Oil, or more accurately, petroleum, may be divided into the following three general categories based on its volatility and viscosity (after Owens, 1977):

1. Liquid or Free-Flowing Oils

   These oils consist of unweathered light crudes, aviation gasoline, diesel fuels, kerosene and most other refined oils. They are generally very volatile and have high rates of evaporation. Characterized by a low viscosity, free-flowing oils will form slicks but rarely emulsions.

2. Very Viscous Oils

   These are heavy crudes, weathered light crudes, and bunker fuels. They are less volatile, will float and form slicks, and readily form emulsions.

3. Semi-Solid or Tarry Oils

   Asphalt and weathered crudes are examples of semi-solid oils. They are non-volatile and very viscous at temperatures below 38°C. Tarry oils may float or sink and do not emulsify, often forming into "tar balls" that may wash up on beaches as the weathered products of an oil spill.

Oils may also be defined as "sweet" (i.e., those with a low sulphur content), "sour", (those with a high sulphur content), "white", (for refined products such as gasoline, kerosene, and diesel fuel), and "black", (for crudes, heavy fuels and Bunker "C" oil) (Fisheries and Environment Canada, 1978). White oils are generally more toxic than crudes but are shorter-lived. Black oils, although not acutely toxic to marine organisms, are more persistent and may last 5 years or more on a low-energy beach.

Crude oil is made up of various hydrocarbons including sulphur, oxygen, carbon and nitrogen. The following three types of hydrocarbons are found in crude oil (after Evans and Rice, 1973):

1. Paraffinic hydrocarbons

   These are saturated chains (i.e., they contain no carbon-carbon double bonds) of single-bond carbon atoms, such as methane and propane and are the least toxic. They are also referred to as alkanes.

2. Naphthenic hydrocarbons

   Examples of naphthenic hydrocarbons are cyclopropane and cyclopentane. Naphthenes are composed of one or more saturated ring structures and may form into long, complex chains. They are insoluble in water.

3. Aromatic hydrocarbons

   The aromatics consist of unsaturated rings, such as benzene and naphthalene, and are the most toxic hydrocarbons found in oil.

Another class of hydrocarbons, called alkenes, is not found in crude oil but is common in many refined petroleum products such as gasoline. Alkenes form straight or branched chains characterized by double-bonded carbon atoms. They are generally more toxic than alkanes, but are less toxic than the aromatics.

### 5.8.2 BEHAVIOUR AND FATE OF PETROLEUM

The behaviour of oil may be predicted by determining its "pour point" (i.e., the temperature below which oil will not flow) (Owens, 1977). If the ambient temperature is below the pour point, the oil will behave like a solid mass. These temperatures range from -57°C to 32°C depending on the specific oil. The majority of oils, however, have a pour point below 0°C and are therefore fluids on water surfaces. Such oils as Bunker C, which has a pour point of -1.1°C to 2°C, may behave as a solid mass in cold ocean water, but may become a viscous liquid or a semi-solid on the shoreline due to the effects of air temperature and solar radiation. This factor may be critical when considering the fact that free-flowing oils readily penetrate beach sediments, but semi-solids tend to remain on the surface and will only penetrate if the sediments are coarse or if ambient temperatures are high.

The rate at which spilled oil degrades is a critical factor not only in determining its effects on the marine and onshore environments but also in developing countermeasure strategies. The agents of degradation (weathering) such as biodegradation (microbial oxidation), evaporation, dissolution, dispersion, etc. are discussed in Sections 5.8.2.1 to 5.8.2.7.

Factors which determine the rates of degradation are the initial composition and physical nature of the oil (volatility, fluidity, and density) and the amount of energy available for degradation. Thermal energy is related to air and water temperature; mechanical energy is a function of wave energy, tides and winds. As the levels of thermal and mechanical energy increase, the rates of weathering increase also.

The rate of degradation is particularly high immediately following exposure of oil to the atmosphere, and is even higher during times of storm-wave activity, when the lighter, and often more toxic fractions are lost to evaporation or dissolved in the water. An oil slick will move downwind at about 3% of the wind speed. At the same time, waves will break up the oil into droplets. Oil, however, tends to dampen breakers and thereby reduces mixing or breakdown of oil on the water surface. Once the oil has reached a quasi-equilibrium with local environmental conditions, weathering decreases rapidly until these conditions change.

A surface slick is accompanied by a sub-surface suspension of oil ("diffusion cloud") accomodated in the water column by dispersion and dissolution. Initially the area of the surface slick exceeds that of the diffusion cloud. Simulation studies suggest, however, that within a few days the radius of the diffusion cloud exceeds that of the surface slick. This spreading of the sub-surface suspension is of considerable significance since it will affect both potential hydrocarbon concentrations in the water column and bioavailability of the oil to pelagic and planktonic biota.

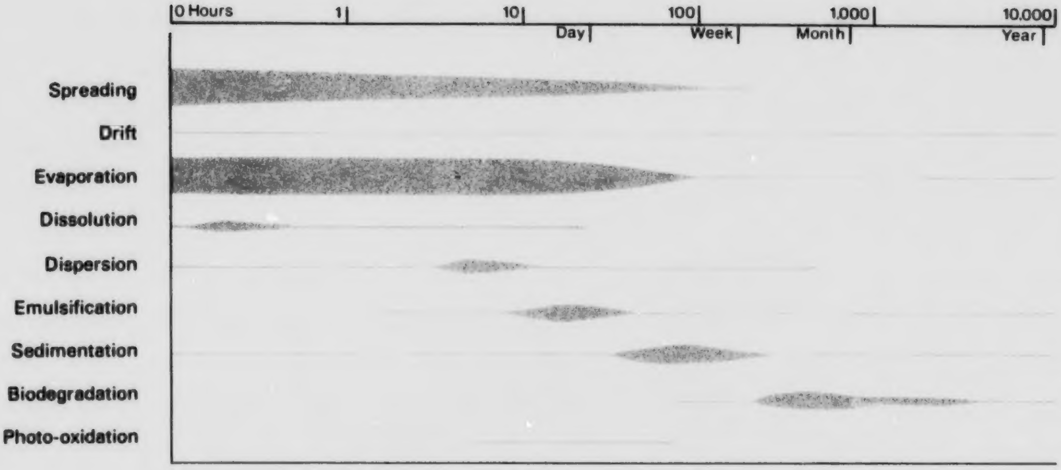
Energy levels which affect weathering may vary locally (e.g., exposed and sheltered shorelines) or regionally (e.g. high and low energy wave environments). Coasts which are open to swell or storm waves are high-energy environments, characterized by physical processes that transmit moderate to high amounts of energy to the littoral zone daily throughout the year. Conversely, low-energy environments are characterized by low rates of weathering. Locally, sheltered shorelines in embayments, inlets, channels and sounds are less exposed to mechanical energy from breaking waves and swashes.

Stranded oil in these environments is protected from the major effects of weathering, and tends to persist longer than it would along the open coast. Oil tends to be stranded only in the upper parts of the intertidal zone, although breaking waves can splash oil beyond the normal limits of wave action. If it is deposited above the mean high water mark, oil will only be eroded or buried by subsequent wave activities on that part of the shoreline. Oil can be buried or eroded, depending on beach dynamics and whether the beach is in an erosional, constructional or equilibrium phase. The net loss or gain of sediment in a beach system results in erosion or burial of oil stranded on that beach. Wave reflections from steep rocky shorelines can prevent deposition in these areas.

Table 5.6 illustrates how the main agents of weathering operate through time in relation to each other.

TABLE 5.6

RATES OF WEATHERING FOR SPILLED OIL



**LINE LENGTH** Probable time span of any process

**LINE WIDTH** Relative magnitude of the process both through time and in relation to other contemporary processes

Source: Exxon, Background Series 12/78

The following sections (5.8.2.1 to 5.8.2.7), unless it is otherwise indicated, are based on information obtained from the Transmountain Pipe Line Co. Ltd. Physical and Chemical Oceanographic Report, Vol. XV, Part 'B'.

### 5.8.2.1 Dissolution

Dissolution is the process whereby certain slightly soluble hydrocarbons (e.g., sulphur compounds) and various mineral salts present in oil are dissolved in the surrounding water. Hydrocarbons vary greatly in their solubility, although hydrocarbons in general have a low solubility in water. Usually low molecular weight components are more soluble than those of high molecular weight, and aromatic hydrocarbons are more soluble than paraffins. Dissolution of the more soluble components competes with evaporation. This competition can result in the enhancement of the middle molecular weight aromatic hydrocarbons over the original distribution of components in the dissolved oil, resulting in an overall increase in toxicity.

Salinity is an important factor in the rate of dissolution. The lower the salinity, the more soluble the oil. In areas of low salinity or in fresh water, oil is more readily diluted and thinned (Owens, 1977). Rates of dissolution are also enhanced by dispersion, as discussed in Section 5.8.2.4.

#### 5.8.2.2 Evaporation

Evaporation is probably the most significant factor in the degradation of spilled oil. Wind speed, air temperature and sea state are the principle environmental factors influencing the evaporation of volatiles (low-boiling point components) from oil surfaces. At 20°C gasoline evaporates approximately 50% of its original volume within 7 to 8 minutes. Many gasoline, kerosene, light fuel oil and light crude oil spills may almost completely disappear after 24 hours. Most crude oils lose about 25% of their volume in the first day, while the heavy crudes lose only about 2% through light-end volatization (Fingas et al., 1978). Rapid evaporation is encouraged by high winds and whitecapping, although the latter process, as mentioned, is dampened by heavy oil overlying the water surface. Evaporation is also a function of the surface area-to-volume ratio of the spilled oil: the larger the ratio, the greater the rate of evaporation. Water temperature has an indirect effect; it can influence the rate of spreading by decreasing the surface area-to-volume ratio.

Emulsification tends to minimize the surface area-to-volume ratio, which in turn tends to minimize evaporation. Evaporation, however, is probably not a significant factor in the weathering of emulsified oil, since most of the volatiles have already been lost by the time emulsification takes place.

### 5.8.2.3 Oxidation

Adsorption of light by oil can induce combination with atmospheric oxygen to form more stable oxygenated compounds. Lower molecular weight compounds are more soluble, while compounds of higher molecular weight usually form into tars or gums.

Photo-oxidation, or photolysis, is a surface process which is dependent on the surface area-to-volume ratio. It is enhanced by the presence of metal ions such as vanadium, and retarded by radical scavengers such as sulphur compounds. Chemical oxidation is limited to the surface area exposed to ultraviolet light, and is enhanced by mineral salts and metal ions. Both forms of oxidation are enhanced by thinner slicks, and may in turn enhance dissolution and emulsion formation.

### 5.8.2.4 Dispersion

Dispersion is caused by agitation, which breaks the oil up into small droplets and spreads them over the water surface or transports them downwards in the water column. The latter is a reversible process, since the large droplets tend to rise rapidly back to the surface. Smaller droplets (less than 1 mm in diameter) may have very long rise times and may be kept in the water column by normal oceanic turbulence. Winds greater than 16 km/h will cause dispersion of the slick into streaks or windrows. Oil may be dispersed vertically to a depth of 80 m and horizontally over a distance of 250 km (Forrester, 1971).

Through dispersion and breakdown of oil components, a greater surface area is exposed. This newly exposed oil undergoes rapid chemical changes (dissolution, oxidation, biodegradation), especially during times of storm wave activity.

### 5.8.2.5 Biodegradation

Over 200 species of bacteria, yeast and filamentous fungi are know to metabolize hydrocarbons. Bacteria can oxidize up to 2 grams of oil per square metre per day. This rate is influenced by the availability of nutrients and oxidation of the water column by water and wave current action. When an oil spill occurs, the number of hydrocarbon utilizing (HCU) bacteria increases. As the metabolically available fractions are used up, these numbers decrease to background levels (Stewart and Marks, 1978). The relative numbers of HCU bacteria in a particular system can be used as an index of petroleum input and hence the impact to that system. The hydrocarbons most rapidly metabolized by HCU bacteria are the middle molecular weight, straight-chain paraffins. Low molecular weight paraffins and aromatics are toxic to the degrading species. Most biodegradation is aerobic and is controlled by the amount of available nutrients, especially phosphates and nitrates. Biodegradation is enhanced by dispersion and large quantities of available oxygen, and is retarded by oil bound in sediments, tarballs, and similar low-oxygen environments. While the most active degradation occurs at temperatures from 20-25°C, it can occur in extremes ranging from -2°C to 70°C. Unlike most agents of weathering, biodegradation occurs on surface oil, dispersed oil and shore-stranded oil. Its products are usually more soluble than the original components.

### 5.8.2.6 Sedimentation

The burial of oil in sediment decreases the rate of degradation by reducing the input of mechanical energy and by insulating the oil from surface radiation. Oil is readily adsorbed by clay and silt, so that in water with a high silt load, adsorption of oil onto the silt particles is probable. Ingestion by filter-feeding organisms and ejection of oil in faeces can also be a significant process in sedimentation. Marine fouling on the surface of tarballs sometimes increases their density and causes sinking.

Some paraffinic hydrocarbons have been known to remain in bottom sediments for 2 years after a spill. Studies of Bunker C oil show that it reaches maximum concentrations in coarse sediments, approximately 1 year after a spill, and declines thereafter. Little diminution was observed in soft sediments after more than 2 years (Scaratt and Zitko, 1972).

Studies of oil decay rates in sand columns indicate that 10% of the oil is oxidized over several months, while the remaining 90% decays much more slowly (Johnston, 1970). A thick oil can prevent sediment redistribution, especially in a low-energy environment, resulting in a decrease in rates of abrasion and erosion. The stability and persistence of hydrocarbons in marine bottom sediments, and the potential for their redistribution to the biosphere through metabolization by benthic organisms, can result in chronic pollution near the spill site. This is likely to occur in areas of high productivity.

Changes in sediments that are difficult to detect, such as decreased nutrient recycling and community metabolism, have been shown to result in the loss of significant contributions to the productivity and stability of an area (Evans and Rice, 1973).

In tidal marshes, the reduced cohesion of bottom sediments caused by the dying of benthic plants and organisms may result in sediment erosion and the subsequent spreading of hydrocarbons to other areas where the process would be repeated.

#### 5.8.2.7 Emulsification

Lower viscosity and low specific gravity oils tend to form oil-in-water emulsions. These are relatively easy for plankton to ingest and they tend to weather quickly. Oils containing asphaltic compounds can form a water-in-oil emulsion, often referred to as "chocolate mousse". Although these emulsions result in lower viscosity, they tend to be very stable and generally inhibit weathering processes. Perhaps the only process available to degrade a water-in-oil emulsion is biodegradation. This process is limited by the bioavailability of nutrients in the emulsion. As weathering progresses, the viscosity of the emulsion increases and the oil becomes less mobile. The eventual fate of emulsions is not fully understood. It is assumed that with increasing viscosity, tarballs are eventually formed, particularly in the presence of sand and debris in the shore zone. Tarball formation decreases the likelihood that organisms will be exposed to toxic components.

### 5.8.3 DATA GAPS - AN ASSESSMENT OF THE ADEQUACY OF AVAILABLE INFORMATION ON THE BEHAVIOUR AND FATE OF PETROLEUM

The ultimate fate of any particular oil spill is always highly speculative due to changing weather patterns, currents, shore types, etc. At least fourteen factors which govern the effects of spilled oil have been identified. They are:

i) type of oil spilled
ii) amount of oil spilled
iii) physiography of spill area
iv) weather conditions at time of spill
v) biota of the area
vi) season of spill
vii) previous exposure of area to oil
viii) exposure to other pollutants
ix) treatment of spill
x) water temperature and other physical properties
xi) tides and currents
xii) salinity and other chemical properties
xiii) distance of spill site from coastal areas
xiv) degree of weathering of oil at sea

(after Straughan, 1971)

The biological effects of spilled oil are covered in Section 3.3.6.

Since the above factors are all variables (and there may be others), the behaviour and fate of any spill can only be determined, in terms of impact and areas affected, in the broadest and most general terms. Any model based on the above factors would be extremely complex and would almost certainly require the use of a computer. Each factor would have to be assigned a numerical value in terms of potential magnitude of impact, sensitivity, mitigating properties etc., to arrive at an overall value for the effect of a spill event on a particular area. It is questionable, however, whether the complexity of such a model would not render it ineffectual in the event of an actual spill.

Specific data gaps with regard to the behaviour and fate of oil are as follows:

### 5.8.3.1 Emulsification

The factors that contribute to emulsion formation are not well understood. According to the Environmental Protection Service (1979), emulsions are formed "as a result of wave action", whereas Herlinveaux (1972) states "sometimes virtually no mixing energy is required for (emulsions) to form; the oil simply takes up sea water."

The eventual fate of emulsions and the factors contributing to their degradation also remain poorly understood. Oil-in-water emulsions show a tendency to coalesce and reform into an oil slick when the water becomes calm. The presence of surface active agents in the oil or chemical dispersants may actually increase the persistence of this type of emulsion. Natural dispersion and weathering processes such as dissolution, oxidation and biodegradation may be accelerated due to the increased surface area-to-volume ratio of oil-in-water emulsions.

Water-in-oil emulsions ("chocolate mousse") commonly contain 50-80% water and may persist for months or even years after a spill, particularly when deposited in shoreline areas (Environmental Protection Service, 1979). Conjecture by some researchers suggests that tarballs may be formed from water-in-oil emulsions in the presence of sand and other sediments in the shore zone, although this remains unproven. Studies conducted by Berridge (1969) have indicated that the stabilization of emulsions is usually the result of formation of complex chemical compounds in the non-volatile residues and is not caused by bacterial activity, marine organisms, or suspended matter.

In view of these various arguments, it is evident that further studies are required to determine with certainty:

a) the factors that lead to the emulsification of oil, particularly water-in-oil emulsions;
b) the eventual fate of emulsions;
c) the factors contributing to the stabilization and degradation of emulsions.

#### 5.8.3.2 Biodegradation

The degradation products of HCU bacteria (oxidized hydrocarbons) and their effects on the marine environment is not well understood. Since some of these products may be more toxic than their original components, further definitive research is required in this area.

#### 5.8.3.3 Dissolution

There is little information available on the solubility of refined petroleum products and crude oils in salt and fresh water. Most solubility data have been obtained through laboratory studies involving pure hydrocarbons. It is difficult to relate laboratory values to a real spill situation, where a large number of factors affect solubility (Fingas et al., 1978). In situ studies are also required to determine the toxicity of dissolved hydrocarbons on marine organisms.

#### 5.8.3.4 Environmental Sensitivity

Not all researchers are in complete agreement as to which environments are most resistant to oil spill pollution. It is generally agreed that steep rocky shorelines in high-energy wave environments are the most resistant to oil spill contamination. The steep slope, relatively small exposed surface area of the substrate, high wave reflectivity, and high-energy transport would seem to indicate that these coastal environments are not susceptible to oil deposition. However, the idea has been advanced that the environments most capable of withstanding attack by additional pollution stresses (i.e., oil spills) are those systems already subjected to energy-requiring stresses and seasonal variability, such as northern temperate estuarine ecosystems (Copeland, 1970). Many estuarine species, however, are already living near their limits of tolerance, and alterations caused by even low levels of pollution could permanently exclude them from the environment. The susceptibility of coastal environments to pollution stresses is not yet firmly established.

### 5.8.4 SPILL MOVEMENT

Trajectory analysis, the process of determining spill movement, may be carried out by manual or computer methods. The most probable movement of oil from potential spill sites can be derived from data on the average or expected speed and direction of winds and currents.

As examples, Figure 5.2 (summer) and Figure 5.3 (winter) depict the most probable distribution of a very large (over 10,000 barrels) spill in southern Hecate Strait.

This spill is plotted for three time periods, representing hypothetical stages of reduced risk with increased weathering:

i) 3 days (diminished toxicity)
ii) 10 days (diminished physical impact)
iii) 30 days (minimum biological impact)

It must be recognized that these simulations are very rough projections based on available data and previous simulations (EPS, 1978; Trans Mtn., 1980b). Further basic data collection, as outlined in Chapter 2, is necessary to refine trajectory projections and determine more accurately the overall probability (% chance) of oilspills of different size contacting land within the time periods noted above. This information is necessary to make recommendations on safety zones, regulations, phasing of drilling operations and pipeline and tanker route locations. To assist contingency planning, spill risk probability data can be presented in the trajectory map format, as a percent probability contour map or in the given below in Table 5.7.

TABLE 5.7

OVERALL PROBABILITY (% CHANCE) OF OIL SPILL CONTACTING LAND

| Spill Site | Within: 3 days | | 10 days | | 30 days | |
|---|---|---|---|---|---|---|
| | Volume of Oil Contacting Land | | | | | |
| | 1000 Bbls | 10,000 Bbls | 1000 Bbls | 10,000 Bbls | 1000 Bbls | 10,000 Bbls |
| A (30 miles offshore) | 2 | 1 | 27 | 12 | 51 | 26 |
| B (50 miles offshore) | N | N | 5 | 2 | 11 | 5 |

N = Less than 0.5%

(After Norton Sound, 1981)

## 5.9 RESOURCES AT RISK

To objectively assess risks for contingency planning, socio-economic and biophysical information needs to be analyzed to determine which resources and habitats are most sensitive to oil pollution. Table 5.8, which has been adapted from Bureau of Land Management (BLM, 1979) gives a rough ranking of the relative effects of oil on different marine habitats. Studies of oil spills have indicated that the greatest impacts are often incurred when oil reaches protected estuaries (i.e., saltmarsh, eelgrass and mud habitats). Open ocean and exposed rock habitats experience lesser impacts.

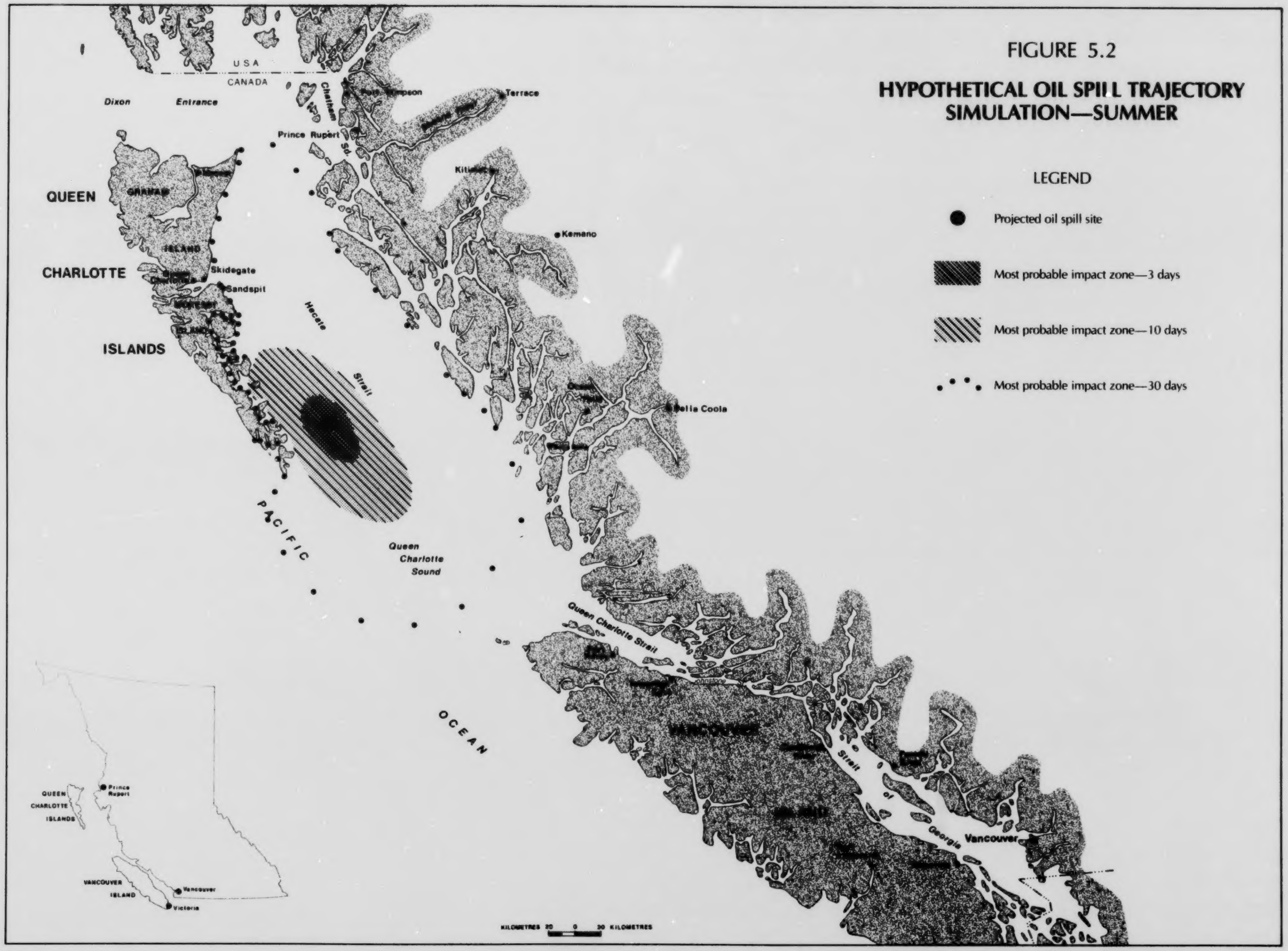


FIGURE 5.2

**HYPOTHETICAL OIL SPILL TRAJECTORY SIMULATION—SUMMER**

LEGEND
● Projected oil spill site
▨ Most probable impact zone—3 days
▨ Most probable impact zone—10 days
• • • Most probable impact zone—30 days
USA
CANADA
Dixon
Entrance
Chatham Sd.
Terrace
Prince Rupert
Kemano
QUEEN
CHARLOTTE
ISLANDS
Skidegate
Sandspit
Hecate
Strait
Bella Coola
PACIFIC
Queen
Charlotte
Sound
OCEAN
Queen Charlotte Strait
Strait
of
Georgia
Vancouver
KILOMETRES 20 0 20 KILOMETRES
QUEEN
CHARLOTTE
ISLANDS
Prince
Rupert
VANCOUVER
ISLAND
Vancouver
Victoria

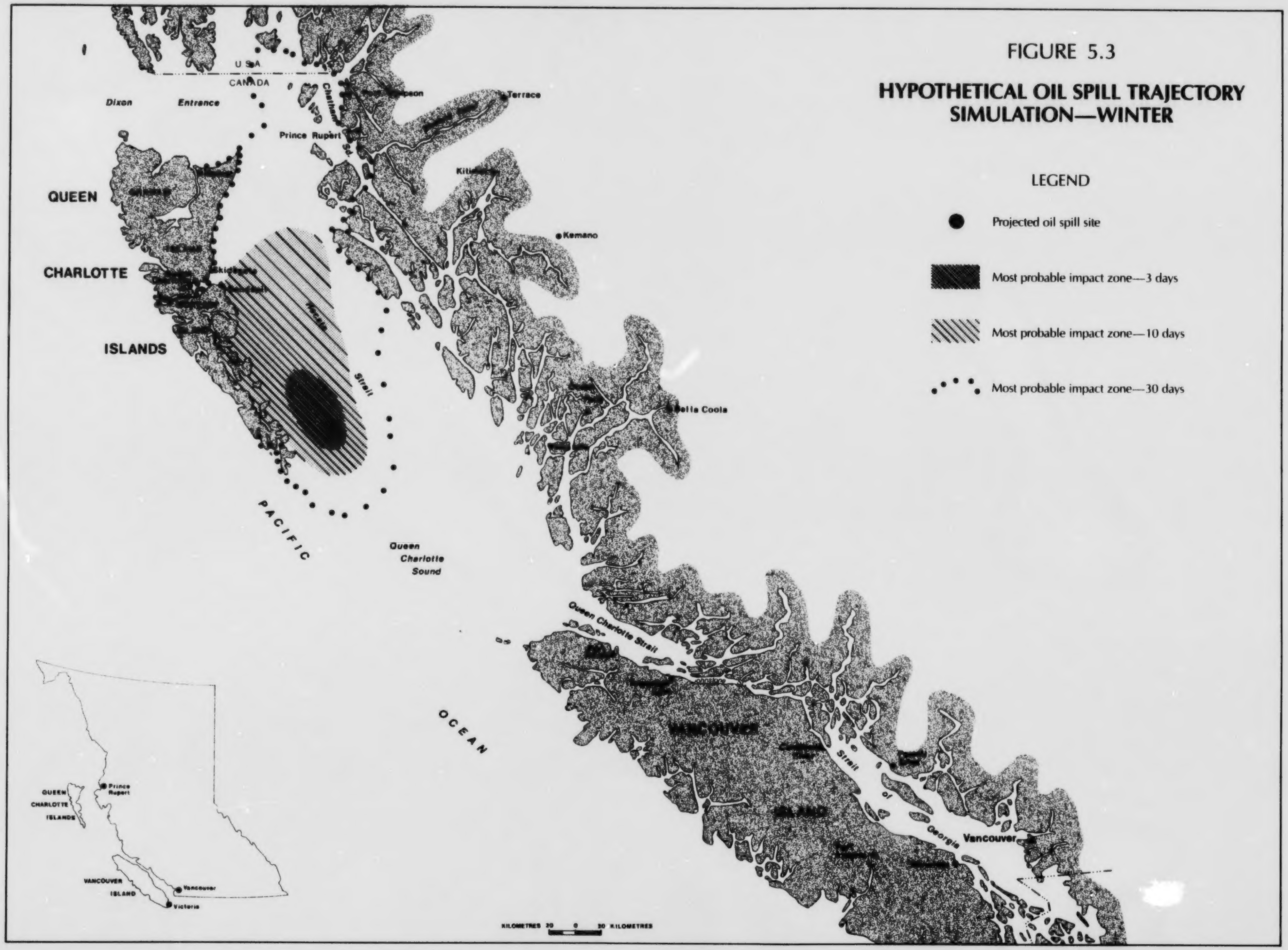


FIGURE 5.3

HYPOTHETICAL OIL SPILL TRAJECTORY SIMULATION—WINTER

LEGEND

● Projected oil spill site

■ Most probable impact zone—3 days

▨ Most probable impact zone—10 days

• • • Most probable impact zone—30 days

U.S.A.
CANADA
Dixon Entrance
Prince Rupert
Chatham Sd.
Port Simpson
Terrace
Kitimat
Kemano
Bella Coola
QUEEN CHARLOTTE ISLANDS
Skidegate
Hecate Strait
PACIFIC OCEAN
Queen Charlotte Sound
Queen Charlotte Strait
VANCOUVER ISLAND
Strait of Georgia
Vancouver
KILOMETRES 20 0 20 KILOMETRES
QUEEN CHARLOTTE ISLANDS
Prince Rupert
VANCOUVER ISLAND
Vancouver
Victoria

## TABLE 5.8

## RELATIVE EFFECTS OF OIL ON MARINE HABITATS
(Source: Adapted from Tables 8.4.3–19 and 21, BLM, 1979)

| HABITAT TYPE | EXPECTED INITIAL PHYSICAL IMPACT (1) | RELATIVE VULNERABILITY RANKING (2) | EXPECTED INITIAL TOXICITY IMPACT (1) | RELATIVE VULNERABILITY RANKING (2) | EXPECTED RECOVERY (3) | RELATIVE TIME RANKING | TOTAL RANKING |
|---|---|---|---|---|---|---|---|
| SALTMARSH | Smothering of vegetation and low flushing rate causing mortality. | SIGNIFICANT<br>9 | Toxic hydrocarbons would cause plant mortality. | SIGNIFICANT<br>7 | Persistence of oil in sediments. Once oil removed, biological succession may be moderate since most organisms reproduce and disperse fairly rapidly. | MODERATE TO SLOW<br>7 | 23 |
| EELGRASS | Beds function as strainers and retainers of oil. | SIGNIFICANT<br>8 | Hydrocarbons retained due to straining effect on plants causing chronic sublethal impacts and some mortality. | SLIGHTLY MODERATE<br>6 | Beds located in sheltered bays, estuarines, and coves and along beaches where currents are slow and wave action moderate to irregular. | MODERATE TO SLOW<br>6 | 20 |
| MUD | Low energy wave or current regime in bay estuaries, and subtidal areas. Oil could be incorporated into mud. | MODERATE<br>7 | Most toxic elements flushed out on outgoing tide. Some hydrocarbons could be absorbed clay particles causing chronic sublethal impacts and some mortality. | SLIGHTLY MODERATE<br>3 | Oil will be deeply mixed by burrowing organisms where degradation will be slow and chronic exposure persistent. | SLOW<br>9 | 19 |
| MIXED - FINE | Oil mixed into surface sediments initially by wave action. Rate of burial quite high. | MODERATE<br>6 | Most toxic elements flushed out on outgoing tide. Some hydrocarbons could be absorbed clay particles causing chronic and sublethal impacts and some mortality. | SLIGHTLY MODERATE<br>4 | Residues can remain for long periods of time due to moderate to poor flushing. | SLOW<br>8 | 18 |
| MIXED - COARSE | Dissolved hydrocarbons could saturate tide pools on falling tide causing tainting or death. | SLIGHT TO MODERATE<br>5 | Tarry residues may smother organisms. Subtidal rock surface unaffected. | SIGNIFICANT<br>9 | Flushing would be rapid, but slower than exposed rock. Heavy coatings may remain in high intertidal. | FAST TO MODERATE<br>4 | 18 |
| ROCK | Dissolved hydrocarbons could saturate tide pools on falling tide causing tainting or death. | SLIGHT TO MODERATE<br>3 | Tarry residues may smother organisms. Subtidal rock surface unaffected. | SIGNIFICANT<br>8 | High wave energy regime. Rapidly flushed. Heavy coatings may remain in high intertidal until next highest tide. | FAST TO MODERATE<br>3 | 14 |

## TABLE 5.8 (Continued)

| HABITAT TYPE | EXPECTED INITIAL PHYSICAL IMPACT | RELATIVE VULNERABILITY RANKING | EXPECTED INITIAL TOXICITY IMPACT | RELATIVE VULNERABILITY RANKING | EXPECTED RECOVERY | RELATIVE TIME RANKING | TOTAL RANKING |
|---|---|---|---|---|---|---|---|
| SAND | Burial of oil preserves oil for release when beach erodes. | MODERATE 4 | Water movement generally sufficient to dilute soluble fractions rapidly. | NONE TO SLIGHT 2 | Oil rapidly flushed away on high wave energy beaches. Moderate wave or current energy beaches and subtidal sediments flush more slowly and may retain some oil for long periods. | FAST TO MODERATE 5 | 11 |
| ALGAE (KELP) | Kelp traps oil in habitat. | MINOR 2 | Hydrocarbons trapped would cause chronic sublethal impacts and some mortality. Habitat most vulnerable from late June through October to November. | SLIGHTLY MODERATE 5 | Beds found where there are strong currents. | RAPID 1 | 8 |
| OPEN WATER | Impact on pelagic phytoplankton and zooplankton dependent on chance event of contacting floating slick. Fish may avoid spill. Not likely oil would accumulate in open water sediments to lethal or sublethal levels. | MINOR 1 | | MINOR 1 | Rapid dispersion and degradation of oil. | FAST 2 | 4 |

EXPLANATION OF TABLE

(1) EXPECTED INITIAL IMPACT TABLE

| IMPACT | PERCENTAGE OF POPULATION KILLED, DISABLED OR PERMANENTLY DISPLACED | MONTHS OF CONTAMINATION OF PREFERRED HABITAT |
|---|---|---|
| MAJOR OR SIGNIFICANT | 40% or more | 3 months or more |
| MODERATE | 15 to 40% | 1 to 3 months |
| MINOR OR SLIGHT | less than 15% | less than 1 month |

(2) RELATIVE VULNERABILITY RANKING

9 = highest vulnerability rank
1 = lowest vulnerability rank

(3) EXPECTED RECOVERY WOULD DEPEND UPON THE SEVERITY OF THE OIL SPILL AND THE EXPOSURE OF THE FORESHORE. FOR AVERAGE CONDITIONS (HECATE STRAIT) SLOW RECOVERY (RANK 6 TO 9) WOULD BE MONTHS TO YEARS: MODERATE RECOVERY (RANK 3 TO 5) WOULD BE WEEKS TO MONTHS; FAST RECOVERY (RANK 1 TO 2) WOULD BE DAYS TO WEEKS. FOR EXPOSED FORESHORE (ROCK, SAND, MIXED-COARSE) ON WEST COAST OF THE QUEEN CHARLOTTES OR VANCOUVER ISLANDS RECOVERY WOULD BE FAST. FOR PROTECTED FORESHORE IN MASSET SOUND, CHATHAM SOUND OR COASTAL INLETS, RECOVERY WOULD BE SLOW TO MODERATE.

Table 5.8 will need to be further refined to incorporate information on locally unique features and resources and cleanup feasibility. This can be used to develop an "Environmental Sensitivity Index" applicable to north coast habitats (see also Section 5.8.3.4).

Further information on the resources at risk are available in Chapters 2 and 3 of this preliminary assessment, in Chapter 4 of Assessment and Planning Division Bulletin No. 9 (Wolferstan, 1981), and in the EPS Countermeasures or Offshore Environment Map Series (1978). The next stage in the contingency planning process will be to priorize and map the habitat types.

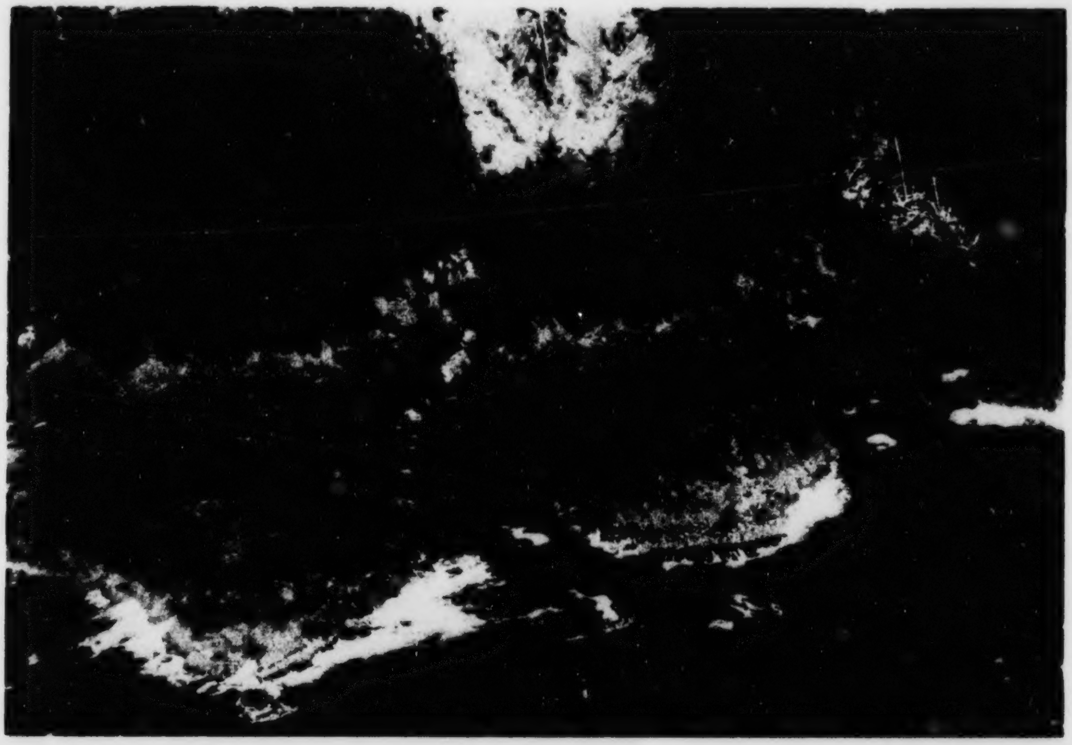


Plate 19: Exposed coastlines are less vulnerable to oil spill impacts than protected estuaries.

*(Photo by Jim Slater)*

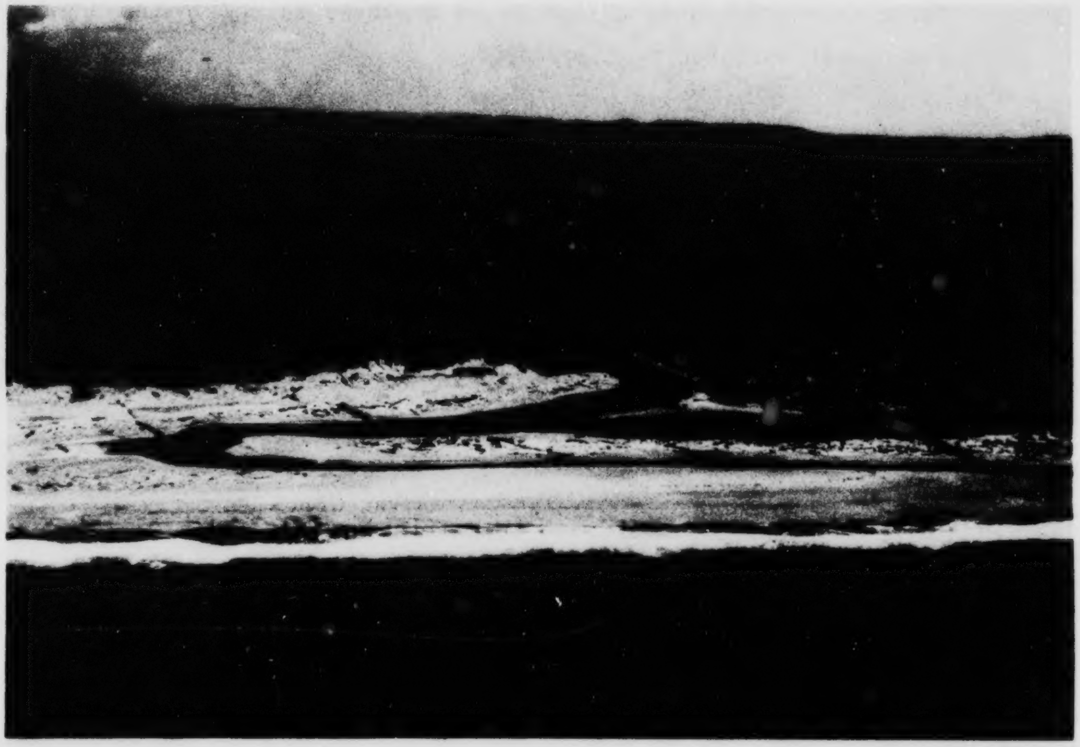


Plate 20: Tidal foreshores and estuaries are particularly vulnerable to oil spills.

*(Photo by Jim Slater)*

## 5.10 OIL SPILL COUNTERMEASURES

To determine which countermeasures are feasible and appropriate for potential spill situations, the social and economic values of resources and vulnerable habitats will need to be enumerated. The main question to be addressed in producing a contingency plan is whether the costs of protecting resources from an oil spill are justified by the anticipated benefits. In responding to an oil spill there are a number of considerations and objectives which need to be taken into account. There are two priorities in this regard:

1. The threat to human health and safety should be minimized. Fires and explosions of oil or gas spills should be prevented. Only

those countermeasures which can be employed safety in the prevailing conditions should be employed.

2. The adverse effects of an oil spill should be minimized by containing and removing all recoverable oil. Control of the source of the spill is the first priority. If this is not possible, the spill must be tracked and monitored and all efforts directed to offshore containment and recovery. Chemical dispersant application or no response options must be considered. If the spill is likely to contact land, the most valuable areas must be protected first and onshore recovery and cleanup countermeasures deployed.

The following sections deal with countermeasures for oil spill cleanup in offshore and onshore areas.

### 5.10.1 OIL SPILL CLEANUP METHODS - ON SITE

Offshore protection (containment and removal, or dispersal) is valuable for sensitive or low-energy environments but is not usually necessary for self-cleaning coasts (e.g., open coast with steep, rocky shoreline). Effective protection requires a knowledge of slick movements, shoreline types and the availability of equipment, material, and manpower. Oil Spill Cleanup Methods include the use of various technologies.

#### 5.10.1.1 Booms

A floating boom is a mechanical barrier extending above and below the water surface and is designed to stop or divert the spread of oil. Booms are used for the following purposes: 1) to enclose a slick and facilitate recovery, 2) to protect certain areas such as harbours, rivers, etc. and 3) to divert oil to areas where recovery is possible (Fingas *et al*., 1978). Booms are only effective when wind and wave conditions are light (i.e., if wave height-to-wave length ratio is less than 0.08), and currents are less than about 1.2 knots (Baker, 1978). The high capital cost and large space requirements of booms limit their effectiveness in oil spill containment.

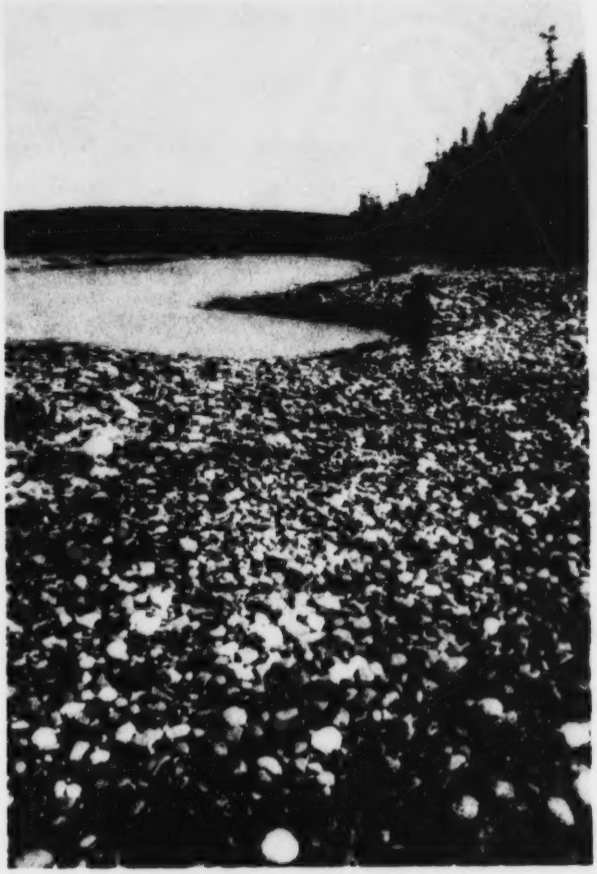


Plate 21: Spill countermeasures will need to be adopted to the unique physical characteristics of vulnerable coastlines.

*(Ministry of Environment Photo)*

This is augmented by intensive labour requirements for deployment of the booms. For example, operators need to:

1. Have booms readily available for use at rigs and supply vessels;
2. Have booms stockpiles near sensitive natural areas likely to be affected;
3. Have a trained crew on standby.

#### 5.10.1.2 Dispersants

Many dispersants contain toxic substances which can have adverse environmental effects exceeding those of oil. The use of any chemicals in oil spill cleanup programs is officially discouraged in most cases, and may only be considered when all other methods have failed, (i.e., when the potential damage to biological and physical resources would be greater if they were not used).

Dispersants contain chemicals which reduce the surface tension between oil and water, resulting in the breakup and dispersal of the slick throughout the water column as an oil-in-water emulsion. Oil will disperse naturally as it weathers; chemical dispersants are designed to accelerate this process. Theoretically, dispersants will increase the opportunity for oxidation, biodegradation and other weathering processes, and reduce immediate danger to waterfowl and other wildlife. They are also used to prevent oil from adhering to solid surfaces such as shoreline substrates and piers.

Modern dispersants are somewhat less toxic than older types used in previous spills, although their use remains a controversial issue. The advantages of dispersant application include:

- Increased rate of oil degradation
- Less tendency for the oil to form tarry residues
- Reduced fire hazard
- Decreased contamination of shorelines
- Decreased impact of oil on waterfowl
- Relatively low cost and labour requirements

The disadvantages are:

- Potential toxic effects to aquatic life
- Increased exposure of organisms to toxic hydrocarbons in the dispersed oil
- Lack of knowledge regarding the fate of dispersed oil

In general, the use of dispersants is discouraged unless all the unknowns have been evaluated. Discussion on dispersant usage quoted from the Oil Spill Intelligence Report (June, 1982) is optional in Appendix 3 of this report.

#### 5.10.1.3 Burning and Wicking Agents

Only relatively thick oil slicks will burn at sea. It is virtually impossible to ignite a thin layer of oil on water because the heat is rapidly drawn off by the water beneath it. Burning agents, such as gasoline and light crude oils, are used to ignite and sustain the cumbustion of spilled oil. Wicking agents, such as straw, wood chips, and treated silica, are used to increase oxygen availability and insulate the burning oil from the water beneath. The possibility of air pollution makes burning feasible only in remote locations.

Other methods, such as sinking agents, chemical barriers, gelling agents, and biological agents are seldom used because of their limited effectiveness or the undesirable side effects to aquatic biota (after Fingas et al., 1978).

### 5.10.1.4 Oil Skimmers

A skimmer can be defined as any mechanical device designed to remove oil from the water surface without causing major alterations to its physical or chemical properties (Fingas et al., 1978). The Environmental Protection Service has identified five generic categories of skimmers:

1. Weir-Type Devices

This type of skimmer takes advantage of gravity to drain oil off the water surface. It consists basically of a weir or dam, a holding tank, and an attachment connected to external pumping equipment. They are most satisfactorily used in calm protected waters such as harbours, lakes, ditches, and some rivers.

2. Suction Skimmers

Suction devises use an external vacuum pump system and are designed to float at the oil-water interface. Due to their compactness and shallow draft, suction skimmers are most useful in shallow water and confined areas such as under docks.

3. Centrifugal Skimmers

This design operates by the creation of a water vortex which draws the oil into a collection area. The oil is then pumped into an oil-water separator for recovery. These devices are not as susceptible to clogging as weir or suction devices, and are most effective for wave heights less than 0.6 m and currents less than 0.6 knots.

#### 4. Submersion Skimmers

This device is usually incorporated into a motorized vessel. Oil in the skimmer's path is forced beneath the surface by an inclined, moving belt. It is then directed toward the mouth of a collection well where it rises to the surface due to its natural buoyancy. The collected oil is then pumped to a storage facility. Submersion devices are most effective for low specific gravity and low viscosity oils and for relatively thin slicks. Recovery rates and oil content of the recovered product are relatively high for this type of apparatus.

#### 5. Sorbent Surface (Oleophilic) Skimmers

These skimmers incorporate a special sorbent or "oleophilic" (oil-loving) surface to which oil can adhere to facilitate its recovery from water. The sorbent surface can be in the form of a drum, disc, belt or rope which is moved continuously through the oil film. The collected oil is then removed by a wiper blade or pressure roller and deposited in an on-board container or removed by a pump. Sorbent surface skimmers operate most effectively on relatively thin slicks.

### 5.10.1.5 Sorbents

Sorbents are most commonly used in the final cleanup of trace amounts of oil or to remove oil from areas inaccessible to skimmers. The three basic classes of sorbents are:

1) Natural organic materials such as peat moss, straw, hay, and sawdust;
2) Mineral-based materials such as vermiculite, perlite and volcanic ash;
3) Synthetic organic sorbents such as rubber, polyester, foam, polystyrene and polyurethane.

Following the recovery of spilled oil, two tasks remain. One is to separate the oil from the water and the other is to dispose of the oil, along with any remaining sorbent materials and other debris recovered in the cleanup program.

Oil may be separated using gravity or settling tanks. Disposal usually involves burning or re-refining. The technology of separation and disposal is not well advanced. Consequently, industry and government research programs are continuing in this direction.

### 5.10.2 OIL SPILL CLEANUP METHODS - ONSHORE

Oil Spill cleanup methods which can be used onshore include the following:

#### 5.10.2.1 Chemical Dispersants

Dispersants can emulsify the oil and consequently retard bacterial degradation rates. The reduction in viscosity can also result in a greater penetration of oil into beach sediments.

#### 5.10.2.2 Hydraulic Dispersion

High pressure hoses may be used to wash oil from coarse sediments, rock surfaces, and man-made structures. Low pressure hydraulic dispersion is preferred in biologically sensitive areas.

#### 5.10.2.3 Steam Cleaning

While this is a more effective variation of hydraulic dispersion, it is more harmful to local flora and fauna.

#### 5.10.2.4 Sandblasting

This method is only recommended for man-made structures.

#### 5.10.2.5 Mixing

Mechanical rakes or harrows have been used for light contamination.

Mixing increases rates of dispersal and degradation. Pushing contaminated sediments into the zone of maximum wave activity is the most effective means of mixing.

#### 5.10.2.6 Removal

Mechanical scrapers combined with elevated graders or front-end loaders may be used, with as little uncontaminated sediment as possible being taken with it. If necessary, the sediment is replaced to prevent adverse alteration of beach equilibrium when large volumes have been removed. Whenever possible, removal is made before burial takes place.

#### 5.10.2.7 Sorbents

Sorbents such as straw, sawdust, bark, peat and vermiculite may be used to absorb oil before it can penetrate beach sediments.

#### 5.10.2.8 Burning

This method has been used on-site with limited success, as it may result in secondary contamination. After burning, a heavy residue remains, and the reduction in viscosity causes the oil to penetrate into sediments and may actually increase contamination (Baker, 1978).

It has been estimated that weather conditions which would allow effective on-site oil spill cleanup occur only 15% of the time in the study area (Fisheries and Environment Canada, 1978). It would seem most practicable, therefore, to base contingency plans on mitigating the onshore effects of spilled oil.

## 5.11 SUMMARY

The risk of blowouts or other offshore exploration activities contributing to major oil spills on the British Columbia coast is not expected to be high. The highest risk of oil spillage is likely to come with product handling and marine transport, should significant quantities of oil be discovered.

The causes of accidents resulting in oil spills are seen to be the result of natural hazards, mechanical failure and human error. Measures which can be taken to reduce the risk of oil spills include improved technology and training and improved maintenance and regulation of offshore activities.

Oil spill contingency plans will need to include comprehensive risk analyses to predict spill probabilities, spill distribution and potential impacts on the resources at risk. The feasibility of employing appropriate countermeasures for different spill scenarios will also need to be considered. Broadly speaking, contingency plans for oil cleanup should emphasize sheltered areas and areas of high productivity.

# CHAPTER 6

# CONCLUSIONS

R. Langford

# CHAPTER 6—CONCLUSIONS

This preliminary environmental assessment has led to a number of observations and conclusions which are applicable to environmental management of the offshore hydrocarbon industry in British Columbia.

As such, they will be used as a basis for further environmental planning and assessment for offshore and related onshore development. In particular, these conclusions will be used to establish and priorize requirements for 1) resource inventory, 2) data collection for answering key questions, 3) environmental regulation, 4) establishment of monitoring programs, and 5) facility planning, onshore and offshore. These activities should be phased to meet the requirements for the exploration stage and subsequently the development stage, should this prove feasible.

In that this document is a preliminary environmental assessment, the conclusions cannot be considered as impact statements but rather as deductive findings based on experiences in other parts of the world, and on existing information in British Columbia.

## 6.1 ENVIRONMENTAL ASSESSMENT AND PLANNING

Impact predictions form the foundation of much of the planning for offshore development. They are used for identifying the resources at risk, planning inventory programs, mapping coastal sensitivities, carrying out risk analyses, developing monitoring programs, designing regulations and contingency plans, and for designing facilities.

The ability to control and manage the impacts of offshore hydrocarbon exploration and development is dependent on the ability to predict, with accuracy, the probable effects this industry will have on environmental resources. Knowledge and experience in predicting impacts has been gained from Scotland, Norway, the Beaufort sea, Labrador, Newfoundland, Nova

Scotia, Alaska, and California. This experience has shown that most environmental impacts have been accurately predicted and can be effectively managed.

The ability to identify and quantify every impact is limited by insufficient or inadequate information. Natural variability or "noise" reduces the effectiveness of much data. Collection of wrong information and utilization of inadequate time spans also negates the usefulness of much data and information. The traditional approach to environmental assessment involves the collection of extensive background data which can produce irrelevant, unnecessary descriptive information. These approaches to impact assessment leave many critical questions unanswered. These may include questions relating to trophic interrelationships, biological sensitivities to oil, life cycle patterns, in situ toxicities, etc. Answers to these and other questions are needed in order to complete impact predictions and thereby make possible, accurate impact management. This inability to deal with important concerns has weakened the effectiveness of such impact assessment studies and requires that other mechanisms be devised to protect the environment against unexpected or unknown effects.

It is generally neither cost effective nor necessary to attempt to inventory all environmental resources at risk, or to understand all interrelationships between oil pollution and impacts on resources. The investigation and/or inventory of key environmental factors at each stage of project development will provide the basis for effective environmental management of such projects.

The United Kingdom has not applied traditional environmental impact assessment to offshore exploration or production. Analysts have concluded that expensive long term baseline studies are impractical for impact predictions and have placed emphasis on monitoring the resources at risk. The Norwegian government has similarly placed emphasis on marine pollution research and monitoring. In particular, the Norwegian government has established an "Ecological Action Plan" which has as its objective the measurement of the effects of oil on shallow water biota along the Norwegian coast (Environment Canada: Cornwall *et al*. 1981).

From the above and other situations it is concluded that environmental assessment cannot be depended upon to answer all the needs of environmental management. Baseline studies, inventories, and fundamental research projects must be carefully designed to provide critical information. Beyond this, their cost effectiveness must be balanced with alternate management techniques such as *comprehensive monitoring programs* which are carried out while exploration and development are underway.

There is a need for the establishment of an information and data forum through which government, industry and academics can coordinate the environmental studies and management of each phase of development. This forum is needed to focus the information requirements and responsibilities during seismic exploration, exploratory drilling and production and associated activities. A further role will be to coordinate the development of a comprehensive monitoring program which will be used to test the effectiveness of the regulatory and management process.

The information needs indentified in this document and summarized below will provide the basis for these activities.

## 6.2 OFFSHORE PHYSICAL AND CHEMICAL ENVIRONMENT

### 6.2.1 PHYSICAL PARAMETERS

It is necessary to identify key information requirements for all phases of offshore exploration and development. The physical environmental factors concluded to be of greatest significance to the offshore industry have been identified for the British Columbia Ministry of Environment by MacLaren Plansearch (1982). These are listed below:

1. Wind speed
2. Wind direction

3. Wind duration
4. Fog
5. Current speed
6. Current direction
7. Wave height
8. Wave period
9. Sea surface elevation
10. Coastal geomorphology
11. Seismicity
12. Bathymetry

Note: These parameters are not listed in order of priority.

Table 6.1 illustrates how these 12 factors interact.

An adequate data base is not yet on hand and must be obtained for these parameters. Their importance has been identified previously in Chapter 2. Tables 6.2 and 6.6 priorize the need for information relating to each of the physical parameters for environmental management (MacLaren Plansearch for Ministry of Environment, 1982).

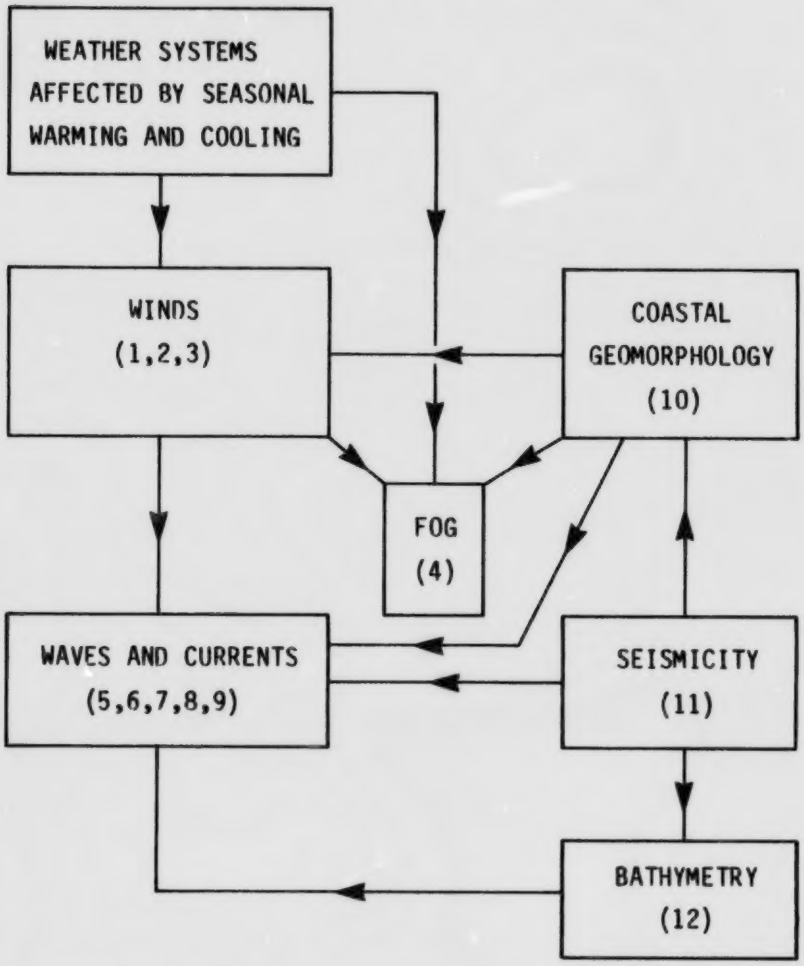
The following conclusions have been reached concerning the physical parameters identified above.

### a) WINDS

On-site, real time, wind recording equipment is needed to make routine measurements of regional wind patterns, including wind direction, wind roses (% occurrences of wind direction) and the duration for a particular "wind event" (e.g., a 35 km/h wind blowing SE over a 10-hour period). Frequencies of major storms, gale warnings, storm warnings and other wind data are also required. These data are available through various north coast weather stations such as Terrace, Prince Rupert, Cape St. James, Langara Point, and Sandspit. Other meteorological data such as storm tracks and maximum

## TABLE 6.1

## PHYSICAL AND METEOROLOGICIAL INFLUENCES ON OFFSHORE PETROLEUM OPERATIONS


WEATHER SYSTEMS AFFECTED BY SEASONAL WARMING AND COOLING
WINDS (1,2,3)
COASTAL GEOMORPHOLOGY (10)
FOG (4)
WAVES AND CURRENTS (5,6,7,8,9)
SEISMICITY (11)
BATHYMETRY (12)

Note: Numbers in parentheses refer to list on previous page. Arrows indicate direction of influence.

## TABLE 6.2

## PRIORITIES FOR PHYSICAL AND CHEMICAL DATA

Examples of the kinds of data used to guide environmental management of offshore developments. The importance of the data to various phases of management is suggested by priority numbers. Priority values are based on the importance of the data in planning for the phases indicated at the heads of the columns. Priorities are: 1 - Essential; 2 - Valuable (i.e., should be collected if possible); 3 - Useful (i.e., worth collecting); 4 - Needed only for scientific completeness; and 5 - Irrelevant (i.e., data not collected routinely). (After MacLaren Plansearch, 1982).

| | WEST COAST | | | | COMMENTS |
|---|---|---|---|---|---|
| | Design and Operation | Contingency | Impact Assessment | Impact Monitoring | |
| **METEOROLOGICAL DATA** | | | | | |
| Wind | | | | | Continuous records for analysis of coherence with shore-based stations. |
| speed | 1 | 1 | 1 | 5 | |
| direction | 1 | 1 | 1 | 5 | |
| Air | | | | | |
| temperature | 2 | 1 | 2 | 5 | |
| humidity | 3 | 3 | 3 | 5 | |
| clouds | 2 | 2 | 3 | 5 | |
| fog | 2 | 2 | 3 | 5 | Can be important because of its affect on visibility. |
| precipitation | 5 | 5 | 4 | 5 | |
| icing potential | 1 | 1 | 4 | 5 | |
| Irradiance | 5 | 2 | 4 | 5 | Affects weathering, biological processes, but can be derived from cloud, and fog data. |
| **PHYSICAL OCEANOGRAPHIC DATA** | | | | | |
| Water | | | | | |
| temperature | 3 | 1 | 1 | 5 | Collect data throughout water column continuously with a quality CTD. Important for determining circulation. |
| salinity | 5 | 5 | 1 | 5 | |
| Current | | | | | |
| speed | 1 | 1 | 1 | 5 | Speed and direction should be measured concurrently with temperature, salinity and wind speed and direction at numerous sites, depths and over time periods long enough to resolve sub-tidal, tidal and supra-tidal components and to determine general circulation patterns (cf. Cannon 1978, Holbrook *et al.*, 1980). |
| direction | 1 | 1 | 1 | 5 | |
| drift card studies | 5 | 1 | 1 | 5 | |
| tracked surface drifters | 5 | 1 | 1 | 5 | |
| Wave | | | | | |
| height | 1 | 1 | 1 | 5 | Can be calculated from wind speed, fetch and duration but can be modified by bottom topography and current, at drilling site. |
| period | 1 | 1 | 1 | 5 | |
| Internal waves | 3 | 3 | 2 | 5 | |
| Sea surface elevation | 1 | 1 | 1 | 5 | Potentially important to distribution of pollutants and biological processes. |
| Geomorphology, especially substrate type | 5 | 1 | 1 | 5 | Needed for input into circulation, slick trajectory, etc. models and for resolution and prediction of low frequency motions. |

monthly and annual wind speeds can be obtained through the Atmospheric Environment Service, Environment Canada, Vancouver. Data records of wind and current observations are available through the Institute of Ocean Sciences, Sidney, British Columbia.

While existing recorded data may be sufficient (though largely scattered and not easily accessible), facilities for gathering direct or on-site wind information remain inadequate for predicting slick movements, rates of oil weathering, and the behaviour of oil in the water column. These data are also necessary in determining the structural requirements of offshore facilities and in safety planning for offshore exploration and development.

### b) FOG

Visibility and navigational safety are impaired by fog, particularly in nearshore regions where the risk of collision or grounding is greatly increased. Stationary offshore facilities can also be threatened by collision with tankers, or even with helicopters and supply ships, especially if poor visibility is combined with rough seas, high winds and precipitation. Fog is more prevalent in inlets, where potential port sites have been targeted. This increases risks to tankers and onshore facilities. In the event of a blowout or a major oil spill, limited visibility due to fog or precipitation would seriously hamper evacuation, rescue, and on-site cleanup operations.

Data on fog for the north coast are available through the Scripps Institute in San Diego, the Northeast Area Remote Sensing System at Woods Hole, Massachusetts, or through the Eastern Pacific Remote Sensing System in Seattle.

It is concluded from the present review that there is inadequate visibility information for the area of reference. Existing data does not adequately provide any kind of effective basis for management for the offshore industry.

## c) WAVES AND CURRENTS

In the North Sea, offshore oil platforms are being designed to withstand the impact of the highest wave expected to come once every 100 years; a wave estimated at 30.5 m (71 m from trough to crest) (Ellers, 1982). It is expected that sea conditions in the study area will be similar to those encountered in the North Sea (Thomson, 1981).

Currents have a significant influence on the trajectories of oil slicks. Strong currents also affect drilling operations, pipeline laying, emergency evacuations and platform installation.

Present knowledge of waves and currents in the area of reference is inadequate. On-site measurements are needed for wave heights and periods, changes in sea surface elevation, and current speed and directions. These data are needed to determine local wave and current regimes. This information is also critical to the establishment of engineering design standards used in all phases of exploration and development.

## d) COASTAL GEOMORPHOLOGY

Coastal landforms influence climate, wind flow patterns, currents, tides, oil retention potentials, biological sensitivities and other important factors.

Existing information on coastal geomorphology is inadequate for the development of comprehensive contingency plans and for sensitivity mapping. The map scale on which shore types and oil retention potentials are currently based are not sufficiently detailed. The scale used by Trans Mountain Pipe Line Co. Ltd. is 1:1,000,000. This scale is not suitable to the offshore hydrocarbon industry.

## e) SEISMICITY

Wave impacts are the main environmental forces which influence offshore structures on the east coast of Canada and those in North Sea. For the west coast of the United States and the north coast of British Columbia, however, seismic forces are concluded to be the major concern (Ellers, 1982 and Yorath, pers. comm.). However, the remoteness of a seismic event occurring during drilling and existing technology designed to minimize the probability of a seismically induced blowout would tend to mitigate this risk considerably (Norton Sound, 1981).

In the 60 years between 1912 and 1973, 62 earthquakes of magnitude 4.0 and greater on the Richter scale were recorded for the north coast region of British Columbia (Rogers 1982). Since most earthquakes in the study area occur beneath the ocean or near the continental margin (Milne et al., 1978), the design, location,and structural capabilities of both offshore and onshore facilities must consider seismic risk as the primary concern for the offshore industry.

Detailed seismic surveys are necessary to provide basic information on geologic hazards in the study area. These studies should include locations of active faults, unstable sediments, and erosional and depositional areas on the continental shelf.

## f) BATHYMETRY

Detailed bathymetric and hydrographic surveys are required to identifty bottom contours and stability of seafloor materials. Since production platforms are likely to be bottom-mounted, or gravity-base structures (Ellers, 1982), seafloor stability will be a critical factor in determining structural requirements. Seafloor stability covers a wide range of factors, including the following:

a) potential for liquefaction of sediments under seismic stress

b) discharge of high-pressure gases and fluids during exploratory drilling
c) foundation sediments with low shear strength
d) seabed sediment transport
e) current scouring
f) areas of active faulting
g) slope stability

Existing information regarding seafloor stability is inadequate with regard to structural design requirements for offshore facilities.

Site-specific studies of current velocities and directions at different ocean depths are necessary for designing offshore rigs. Existing bathymetric information is incomplete and inadequate for detailed analysis of engineering and biological implications.

### 6.2.2 CHEMICAL PARAMETERS

The following chemical parameters have been identified as priority concerns requiring studies prior to development of offshore resources.

#### 1) Chlorophyll *a*

The distribution of chlorophyll *a* in coastal regions is indicative of areas of high primary productivity (e.g., algal blooms) and may coincide with fish and seabird feeding grounds (Borstad and Brown, 1981).

Remotely sensed data on the distribution of chlorophyll *a* along the outer British Columbia coast has been archived (e.g., Scripps Institute, San Diego), but at present are neither readily accessible nor readily interpreted for the North Coast area.

### 2) Drilling Fluids

Drilling fluids contain a number of toxic substances and heavy metals which are harmful to marine organisms. The toxic effects of drilling fluids and satisfactory methods for their detection and disposal remain as questions to be addressed in further studies.

### 3) Hydrocarbons

Data on background levels of hydrocarbon concentrations are necessary to determine quantitatively what constitutes a polluted or contaminated state. Studies and planning to form a data base for developing such criteria are presently inadequate.

### 4) Other Concerns

Other chemical parameters which may not constitute priority concerns when considered separately could nevertheless be of importance when considered in concert. Four of these have been identified for which present knowledge remains inadequate for management and planning for the offshore industry.

Nutrients, trace metals, dissolved oxygen, and salinity all contribute significantly to the biological productivity of a particular area. Knowledge of the baseline levels of these parameters and their role in biological interrelationships in the North Coast area is inadequate. Table 6.3 priorizes the need for chemical data for environmental management of offshore development.

## TABLE 6.3

## PRIORITIES FOR CHEMICAL OCEANOGRAPHIC DATA

Examples of the kinds of data used to guide environmental management of offshore developments. The importance of the data to various phases of management is suggested by priority numbers. Priority values were based on the importance of the data in planning for the phases indicated at the heads of the columns. Priorities are: 1 - Essential; 2 - Valuable (i.e., should be collected if possible); 3 - Useful (i.e., worth collecting); 4 - Needed only for scientific completeness; and 5 - Irrelevant (i.e., data not collected routinely). (After MacLaren Plansearch, 1982).

| | WEST COAST | | | | COMMENTS |
|---|---|---|---|---|---|
| | Design and Operation | Contingency | Impact Assessment | Impact Monitoring | |
| CHEMICAL OCEANOGRAPHIC DATA | | | | | |
| Nutrient Concentrations | 5 | 3 | 3 | 5 | |
| Suspended Particulate Matter | 5 | 3 | 3 | 3 | |
| Pollutant Concentrations | | | | | In water, sediments and biota |
| trace and heavy metals | 5 | 5 | 4 | 2 | Quantities discharged usually negligible because of dilution. Identifiable toxic chemicals used routinely on rig including lubricants, cleaners/ disinfectants etc. Also includes toxic hydrocarbons in formation water, etc. not included in other categories. |
| total hydrocarbons | 5 | 5 | 4 | 5 | |
| alkanes | 5 | 5 | 4 | 5 | |
| PAH | 5 | 5 | 4 | 1 | |
| polar compounds | 5 | 5 | 4 | 2 | |
| biocides | 5 | 5 | 5 | 2 | |
| other | 5 | 5 | 5 | 2 | |
| Indicator compounds | 5 | 5 | 2 | 1 | |

## 6.3 BIOLOGICAL ENVIRONMENT

The conclusions drawn here are divided into routine and non-routine impacts which occur during various phases of development.

### 6.3.1 ROUTINE IMPACTS

Conclusions regarding routine impacts are presented in Table 6.4.

### 6.3.2 NON-ROUTINE IMPACTS

Five categories of impacts on biological groups caused by oil spills have been identified and discussed in Chapter 3. They are as follows:

1. Direct lethal toxicity
2. Sublethal effects
3. Direct coating effects
4. Incorporation
5. Habital alteration

## TABLE 6.4

## CONCLUSIONS—BIOLOGICAL IMPACTS

Impacts Common to all Phases of Development

1) Waterborne noise associated with ship traffic, exploration and development may affect commmunication and behaviour patterns of whales.

2) Aerial disturbance of waterfowl causes some nesting birds to abandon their nests. Air traffic should be routed to avoid sensitive colonies. (Minimum flight paths are required.) Air traffic may also disturb sea lion rookeries or haulouts.

3) Concern has been expressed relating to possible interference with the fishing industry, including net and equipment loss due to the disposal of solid wastes at sea. These problems can be controlled through waste management legislation and enforcement.

4) Sewage treatment and disposal is not seen as a major concern except if disposal occurs in an enclosed area. Primary treatment should be a development requirement.

5) Minor fuel spills are potentially lethal to organisms. This may become significant in enclosed waterways. Indigenous communities can be altered. Tainting and sublethal physiological effects are of concern and require detailed evaluation. Fuel handling must be carefully regulated, and effective cleanup procedures must be established.

TABLE 6.4 (Continued)

6) Airborne emissions are not considered to be of significant concern offshore.

Impacts Due to Seismic Phase

1. Seismic testing may affect populations of ringed seals. Concern has been noted regarding the effects of noise on the migration patterns of whales. Time windows may be required if this is shown to be a valid concern.

Impacts Due to Exploratory Drilling Phase

1. Disposal of toxic drill fluids is of major concern in areas of low flushing rates or high sensitivity; regulations need to be developed and enforced.

2. Turbidity plumes may decrease productivity in restricted environments.

3. Blowout prevention fluids are highly toxic; disposal should be regulated as per disposal of dangerous substances.

4. Localized disturbances result from glory hole dredging. Alterations in benthic communities occur. Impacts which are due to habitat destruction, siltation, and smothering, are minimal.

5. Gas flaring is of concern near bird feeding or nesting areas. The extent of this impact has not yet been described in the literature.

Impacts Due to Development Phase

1. Biological impacts associated with burying marine pipelines are not considered to be great. Local siltation causes mortality to some benthic organisms, therefore sensitive intertidal areas should be avoided.

TABLE 6.4 (Continued)

Impacts Due to Production Phase

1. The discharge of oily ballast water is a major source of entry for petroleum into the marine environment. Chronic contamination of enclosed sensitive areas is of concern. Enforcement of standards for discharge of oily ballast water is required.

2. Formation water discharge requires regulation. Standards for marine disposal of oil contaminated formation waters are needed to avoid impacts of oil and hypersaline solutions.

It is concluded that the impacts of routine operations are not great when adequate regulation and enforcement is made part of an environmental plan. Monitoring and detailed site-specific assessment are considered to be integral parts of a management plan.

Major biological classes affected by non-routine impacts are as follows:

Marine bacteria show shifts in class composition in response to hydrocarbon contamination. Permanent or significant impacts are unlikely to occur. Natural population dispersal and variability renders investigation of these organisms difficult, making impact assessment expensive.

Phytoplankton are unlikely to show significant alterations in populations. Species composition may change but the cause of these changes would be difficult to attribute to oil spills. Effects on higher trophic levels which are dependent on phytoplankton will likely be undetectable.

Zooplankton do not show significant alterations in population numbers near oil spills. Detection of impacts due to oil spills is difficult or improbable.

Marine plants in intertidal areas are significantly affected by oil. Species which do not produce muco-polysaccharides are the most vulnerable, therefore kelp is least affected while eelgrass is greatly affected. Estuarine sheltered habitats have high retention rates and are therefore susceptible to damage from oil spills. Protection of these sensitive areas is of greatest importance in contingency planning.

Marine invertebrates are economically important in British Columbia. Oil related deaths may be high following exposure to a spill. Mortality to egg and larval forms is difficult to evaluate. As the bioaccumulation of hydrocarbons is not well understood, its importance merits further intensive study. Tainting, as discussed below under "Fish" also applies to some food species of invertebrates.

Fish show avoidance behaviour in the presence of oil. Fish kills have therefore been reported only in instances where fish are trapped in enclosed contaminated areas. Some question exists as to whether salmon would attempt to migrate through a contaminated area. Pacific herring are vulnerable in that their eggs are laid on eelgrass, making these eggs susceptible to oiling.

Fish may be adversely affected in all five categories (i.e., direct lethal toxicity, sublethal effects, direct coating, incorporation and habitat alteration). Although natural variations in stock levels would likely preclude statistical proof of significant stock reduction from oil spills it is possible that numbers of commercially important species could be lethally or sublethally affected by a major oil spill.

Potentially, the most damaging affect of a major oil spill would be the tainting of fish flesh. Information on the likelihood of fish tainting is lacking.

Marine birds are notably susceptible to mortality from oil spills. Sea ducks and other alcids are most vulnerable. There is a lack of adequate information relating to offshore feeding areas of sea birds. This information is needed immediately for use in evaluation of proposed drilling sites. Nesting sites are extremely sensitive areas and require stringent protection.

Marine mammals may exhibit avoidance behaviour near oil spills. It has not been determined which species are most likely to avoid spilled oil and which are least likely to. Seals, sea lions and sea otters are adversely affected by oil in laboratory experiments. Mammals which depend on their pelt for insulation are most susceptible (i.e., sea otters and fur seals). Mortality is caused by the loss of body heat. Detailed mapping of haulouts and breeding areas is required for protection of important sites.

### 6.3.3 BIOLOGICAL INVESTIGATIONS

Impacts of routine oil and gas exploration and development can largely be controlled through proper planning and regulation. This requires that a number of important biological factors be investigated. Tables 6.5 and 6.6, respectively list biological and other related information which is required for various aspects of environmental planning and regulation. Priority needs are given so that blanket baseline inventories which are expensive and non-essential can be avoided.

## TABLE 6.5

## PRIORITIES FOR BIOLOGICAL DATA

Examples of the kinds of data used to guide environmental management of offshore developments. The importance of the data to various phases of management is suggested by priority numbers. Priority values were based on the importance of the data in planning for the phases indicated at the heads of the columns. Priorities are: 1 - Essential; 2 - Valuable (i.e., should be collected if possible); 3 - Useful (i.e., worth collecting); 4 - Needed only for scientific completeness; and 5 - Irrelevant, (i.e., data not collected routinely). (After MacLaren Plansearch, 1982).

| | WEST COAST | | | | COMMENTS |
|---|---|---|---|---|---|
| | Design and Operation | Contingency | Impact Assessment | Impact Monitoring | |
| BIOLOGICAL DATA | | | | | |
| Phytoplankton | | | | | Annual cycle and areal variation of listed parameters. |
| biomass (carbon or extracted chlorophyll) | 5 | 5 | 4 | 3 | |
| species composition | 5 | 5 | 4 | 4 | |
| productivity | 5 | 3 | 2 | 3 | |
| chlorophyll concentration (*in vivo*) | 5 | 3 | 1 | 5 | Preferably measured continuously with temperature and salinity. |
| nutrient concentration | 5 | 3 | 3 | 5 | |
| Bacteria | | | | | Annual cycle and areal variation of listed parameters. |
| numbers | 5 | 5 | 4 | 5 | |
| biomass | 5 | 3 | 3 | 5 | Fraction of oleoclastic bacteria. |
| species composition | 5 | 2 | 3 | 1 | |
| productivity | 5 | 2 | 3 | 5 | |
| "heterotophic and oleoclastic potential" | 5 | 3 | 3 | 2 | |
| oxygen | 5 | 3 | 3 | 3 | |
| Zooplankton | | | | | Includes meroplankton but not ichthyoplankton. Annual and areal variation of listed parameters. Difficult to determine. |
| biomass | 5 | 3 | 3 | 5 | |
| species composition | 5 | 5 | 3 | 4 | |
| productivity | 5 | 5 | 3 | 5 | |
| physiological indicators | 5 | 5 | 3 | 1 | |
| Fish | | | | | Annual and areal variation of listed parameters. |
| biomass adults | 5 | 5 | 4 | 5 | |
| species composition adults | 5 | 5 | 4 | 3 | |
| behaviour | 5 | 2 | 2 | 5 | |
| life history data of key species | | | | | |
| eggs | 5 | 1 | 1 | 5 | |
| larvae/ichthyplankton | 5 | 1 | 1 | 5 | |
| juveniles | 5 | 1 | 1 | 5 | Difficult to sample. |
| adults | 5 | 3 | 3 | 3 | Age class distribution. |
| productivity | 5 | 5 | 4 | 5 | Must be determined indirectly. |
| fecundity | 5 | 5 | 4 | 2 | |
| other | 5 | 5 | 4 | 1 | Histology, epidemiology, parasitology, physiology. |

# TABLE 6.5 (Continued)

| | WEST COAST | | | | COMMENTS |
|---|---|---|---|---|---|
| | Design and Operation | Contingency | Impact Assessment | Impact Monitoring | |
| Seabirds | | | | | Annual cycle and areal variation. |
| numbers and species composition | 5 | 1 | 1 | 3 | |
| location and size of colonies | 5 | 1 | 1 | 3 | |
| physiological responses | 5 | 5 | 5 | 1 | |
| Marine Mammals | | | | | Annual cycle and areal variation. |
| numbers and species composition | 5 | 1 | 1 | 3 | |
| location of breeding areas, colonies, feeding areas | 5 | 1 | 1 | 3 | |
| Benthos | | | | | This is an assemblage of organisms that is at least as complicated as plankton, but it has been included under one heading.<br>Indicator species. |
| numbers | 5 | 3 | 4 | 3 | |
| biomass | 5 | 2 | 2 | 2 | |
| species composition | 1 | 2 | 2 | 1 | |
| life history | 5 | 3 | 2 | 5 | |
| productivity | 5 | 5 | 3 | 2 | Difficult to determine. |
| habitat description | 1 | 5 | 2 | 5 | |
| commercial species | 1 | 1 | 1 | 1 | |
| other | 5 | 5 | 3 | 2 | Histology, parasitology, physiology, fecundity, etc. |
| Resources | 5 | 1 | 1 | 3 | |
| Biota | 5 | 1 | 1 | 3 | |
| Biosensitivity | 5 | 1 | 1 | 2 | |

## TABLE 6.6

## OTHER INFORMATION PRIORITIES

Examples of the kinds of data used to guide environmental management of offshore developments. The importance of the data to various phases of management is suggested by priority numbers. Priority values were based on the importance of the data in planning for the phases indicated at the heads of the columns. Priorities are: 1 - Essential; 2 - Valuable (i.e., should be collected if possible); 3 - Useful (i.e., worth collecting); 4 -Needed only for scientific completeness; and 5 - Irrelevant, (i.e., data not collected routinely). (After MacLaren Plansearch, 1982).

| | WEST COAST | | | | COMMENTS |
|---|---|---|---|---|---|
| | Design and Operation | Contingency | Impact Assessment | Impact Monitoring | |
| RIG AND SUPPLY VESSELS | | | | | Much of this information will only be known after the project commences. |
| Composition and volume of mud and cuttings discharged and depth of discharge | - | 5 | 1 | 1 | |
| Composition and volume of formation water discharged | - | 5 | 1 | 1 | |
| Composition of formation hydrocarbons | - | 5 | 1 | 1 | |
| Frequency and duration of flaring | - | 5 | 1 | 1 | |
| Biocides used in drilling mud | - | 5 | 1 | 1 | |
| Composition and volume of grey water | - | 5 | 1 | 1 | |
| Atmospheric emissions | - | 5 | 3 | 1 | |
| Noise | - | 5 | 3 | 3 | |
| Solid waste | - | 5 | 2 | 1 | Mainly aesthetics, but floating and sunken trash can foul fishing gear, or kill biota. |
| Other effluents | - | 5 | 1 | 1 | Unknown components that may prove to be problems. |
| OTHER DATA | | | | | |
| Toxicity of hydrocarbons, biocides, metals, etc. to key biota under realistic conditions | 5 | 1 | 1 | 5 | This data gap is common to most industrial developments affecting the marine environment. |
| Ship traffic | 2 | 1 | 3 | 5 | Risk analysis. |
| Fishing activity | 2 | 1 | 2 | 5 | Risk analysis and potential impact. |
| Formation pressure | 1 | 2 | 1 | 5 | Risk analysis. |
| Formation geology and geophysics | 1 | 3 | 1 | 5 | Risk analysis. |
| Seismicity | 1 | 1 | 1 | 4 | Risk analysis and engineering design. |

## 6.4 ONSHORE IMPACTS

Environmental assessment of offshore petroleum development has frequently focussed on the potential impacts of oil spills and blowouts. More recently it has been found that significant impacts are more likely to occur during construction and operation of onshore facilities rather than during routine offshore operations (Brassard et al., 1981; Baldwin and Baldwin, 1975). This has resulted in the development of a variety of approaches to managing the onshore effects of this industry (U.S. Department of the Interior 1979).

Some onshore environmental impacts may result from the construction and operation of facilities associated or induced by offshore development (gas processing plants, roads, waste disposal services). Further conclusions regarding onshore impacts are presented below and are summarized in Table 6.7.

### 6.4.1 CONFLICTS WITH EXISTING ACTIVITIES

The potential for conflict between offshore hydrocarbon development and other coastal activities such as fishing or recreation is of primary concern. Offshore and associated onshore facilities can affect existing activities and may limit future resource use opportunities (e.g. commitment of an area to heavy industrial use will reduce options for recreational pursuits in that area).

The following activities are those most likely to be affected:

a. Fishing - Offshore development can affect fishing through:
   - reducing the land/water habitat base (i.e., loss of wetlands and estuaries through development);
   - competition for marine services, port space and workers;
   - gear damage and vessel traffic conflicts from rig servicing vessels and/or tankers;
   - direct interference with limited portions of fishing grounds.

b. Recreation and Tourism - The impacts of offshore development on recreation and tourism are difficult to predict since they would likely be indirect. Impacts may include population growth, which could put pressure on available recreational opportunities, or a reduction in the scenic value of areas hit by an oil spill. Potential impacts of spills and routine operations on recreation and tourism should be assessed in more detail.

c. Archaeological/Heritage Sites - Archaeological and heritage sites along the coast and in onshore servicing areas are vulnerable to disturbance and should be considered in facility siting and contingency planning.

d. Navigation - Congestion may occur in coastal harbours and waterways due to increased vessel movements. A vessel traffic management system may be necessary if this problem develops.

The coastal communities of British Columbia rely primarily on coastal resource-based activities. A thorough investigation into the possible consequences of offshore development for these activities is required. Examples are available to show how these indirect impacts can be accounted for through planning, and mitigation and compensation measures (Alaska, Georges Bank, Norway, Eastern Canada). Those individuals involved in existing B.C. coastal activities (e.g., fishermen, recreational tour operators) should have the opportunity to identify their concerns for inclusion in the evaluation of and planning for offshore development.

### 6.4.2 WATER QUALITY

Water quality degradation may occur from increased runoff and siltation during site preparation and construction. Impacts of new housing, transportation corridors, waste disposal sites, and ancillary industries, may also reduce water quality. Impacts can be minimized through proper facility siting and through surveillance and monitoring of construction activities.

Since flat, well-drained coastal industrial sites are scarce in British Columbia, proposals to fill or dredge coastal areas to create suitable sites may be made. Land filling, dredging and wharf construction alienate historic land use patterns and may cause loss of particular habitats. Such alterations should not be permitted in estuaries, saltmarshes and other sensitive and productive habitats. While most of these activities are already regulated to some degree, overall siting and operational guidelines are needed to address cumulative impacts.

Long-term, continuous and generally low-level sources of coastal water pollution can be expected over the 20-30 year life of a production field (Cook Inlet, 1980; Kramer et al., 1981). These include produced waters (from processing facilities), ballast water discharge, leaks and small spills. Although specific discharges will require permits, cumulative long-term effects must also be monitored. Due to the potential scale of development, ambient water quality standards may have to be developed to ensure acceptable water quality in coastal waters adjacent to onshore facilities.

### 6.4.3 AIR EMISSIONS, LIGHT AND NOISE

Air emissions during construction and operation of onshore facilities may have localized impacts on air quality depending on the location and types of facilities. Prevailing climatic conditions render British Columbia coastal areas susceptible to air pollution problems (Fisheries and Environment, 1978). Onshore facilities (e.g. tank farms) are sources of a variety of air emissions and should be sited carefully to avoid local or regional problems. Ambient air quality standards will be required if a variety of processing and/or storage facilties are proposed.

### 6.4.4 ONSHORE PLANNING AND MANAGEMENT

Comprehensive environmental planning within the context of an overall onshore development strategy, including social, economic and environmental objectives, is required to minimize the impacts of onshore development. In the pre-exploration phase, planners will require information on: soils, geology, hydrology, fish, wildlife, coastal circulation, flushing, coastal geomorphology, land tenure, land and water uses, other development proposals in the area, port facilities, community composition, local facilities and services, existing planning policies and on coastal industries (fishing, mariculture, recreation, tourism). This information is needed to form the basis for identifying environmental and resource use issues and for choosing an appropriate planning strategy.

Industry's primary goal in planning onshore facilities is economic efficiency. Onshore development is influenced or controlled through industry/government agreements, application of laws and standards, permit stipulations, regional planning programs and through facility construction and operational guidelines. In British Columbia, these guidelines should include the following elements:

- the identification of preferred development and conservation zones based on environmental, social and economic criteria;
- guidelines for facility design;
- requirements and incentives for the clustering of industries and the sharing of facilities where appropriate to minimize the area of disturbance;
- incentives to encourage inland facilities where coastal siting poses environmental problems;
- construction guidelines to minimize environmental disturbance.

An analysis of impacts and associated costs and benefits is difficult because the location, scale and type of hydrocarbon activity is uncertain in the early phases. This uncertainty is due, in part, to the range of alternative strategies for the extraction, transportation and processing of oil and gas reserves. Government agencies will be able to influence the design, location and timing of development to achieve maximum benefits and minimum adverse impacts for the province through laws, agreements and regulations pertaining to the following elements:

a. Mitigation/Compensation - mitigation measures will be implemented to reduce adverse impacts of particular activities; compensation programs will redress losses due to unavoidable impacts

b. Identification of Sensitive and Significant Areas - this will aid in the preparation of facility siting and design guidelines, the identification of acceptable development areas and the development of contingency plans.

c. Environmental Protection Standards - environmental quality can be maintained through:

    i) permitting systems for discharges and emissions;
    ii) the maintenance of ambient air and water quality standards;
    iii) operational guidelines which require environmentally sound construction and operation practices (e.g., revegetation of disturbed areas).

d. Project Implementation - monitoring programs will be designed to check the levels of environmental disturbance; surveillance programs will ensure that the project is proceeding according to the terms and condition of approval.

Offshore hydrocarbon development could bring substantial environmental, social and economic changes to those British Columbia communities adjacent to offshore fields. The early involvement of these communities in project assessment, planning and management will help to maximize the benefits and minimize the adverse impacts of oil and gas activities. Public information will also increase understanding of the objectives of offshore development and its associated environmental, social and economic consequences.

## TABLE 6.7

## CONCLUSIONS—ONSHORE IMPACTS

| Issue | Significance | Comment |
|---|---|---|
| A. EXPLORATION PHASE | | |
| 1. Temporary Service Base: general (e.g., vegetation removal, terrain and soil disturbance, paving, land fill). | Little impact if built at an existing port (likely in B.C.); more significant if a new site is developed. | The fact that the base may be expanded if there is an offshore find should be considered in siting the service base. |
| 2. Temporary Service Base Construction: shoreline alteration through dredging, filling and wharf construction. | These activities can alter harbour flushing and circulation patterns, thus causing water quality problems; direct habitat disturbance may also occur. | Shoreline disturbance should be minimized and construction in sensitive and significant habitats (e.g., estuaries) should be avoided. |
| 3. Temporary Service Base Construction: erosion, siltation, run-off resulting from land grading, filling and alteration of drainage patterns. | These impacts can have significant localized effects on water quality. | Most problems can be controlled with proper construction practices. |
| 4. Temporary Service Base Construction and Operation: production of solid wastes. | Amounts are not significant in the exploration phase. | Solid wastes will not be a problem with proper disposal. |
| 5. Temporary Service Base Construction and Operation: air emissions, noise, visual impacts. | These are minor impacts; their significance will depend on adjacent land and water uses (e.g., residential, wildlife). | These "nuisance" factors should be considered in siting and design of facilities. |
| 6. Operation of Service Vessels: discharge of bilge water, ballast water and sewage water. | Discharge of water contaminated with oil or metallic components can have localized adverse effects especially in sheltered harbour waters; impacts will depend on the habitats affected. | Ballast and bilge water should not be discharged in harbour areas (especially if there are other industries in the area); onshore treatment of waste waters before discharge may be necessary to prevent pollution problems. |
| 7. Offshore Rigs: freshwater requirements. | This is not significant since requirements are not high. | B.C. coastal communities are generally well-supplied with freshwater. |
| 8. Offshore Rigs: Solid waste disposal onshore. | This is of minor concern, although quantities of waste from rigs will be greater than from shore facilities. | Non-hazardous wastes can be handled in local landfills; special treatment and disposal may be required for special wastes such as oiled drill cuttings and drilling fluids. |
| 9. Ancillary and Induced Activities: general. (e.g., drilling fluid companies, tool companies). | These are of minor concern during the exploration stage unless new coastal sites are needed. | Indirect impacts of the development of various small industries on land, water and air resources should be considered in impact assessment and project planning. |

## TABLE 6.7 (Continued)

| Issue | Significance | Comment |
|---|---|---|
| B. DEVELOPMENT PHASE | | |
| 1. Permanent Service Base Construction and Operation: general. See A1 to A8. Impacts will be similar to those identified for a temporary service base, but will be on a larger scale and at a greater level of intensity. Of particular concern are run-off, siltation, air emissions, shoreline alteration, habitat loss, wildlife disturbance and visual impacts. | The need for a large waterfront site may be of concern if alterations to the shoreline or a sensitive coastal habitat are proposed. | As with the temporary service base, good siting and design of the servicing facilities and the use of environmentally sound site preparation and construction practices will minimize environmental impacts. |
| 2. Oil or Gas Pipeline Construction: landfall. Impacts are similar to those of any coastal facility; activities of concern are dredging, filling and construction of shoreline structures. | Impacts will depend on the site. | Pipeline landfalls should be sited away from sensitive habitat areas. Impacts at the landfall site would be assessed in the review of the entire pipeline. |
| 3. Overland Pipeline Construction: activities can have impacts on terrain, soils, vegetation and wildlife. | The significance of impacts will depend on the pipeline route; aquatic habitats (rivers, floodplains) are particularly sensitive. Slope stability and erosion potential are among the concerns. | Many impacts can be avoided or mitigated through careful route selection, planning and the use of environmentally sensitive contruction and restoration techniques. |
| 4. Marine Terminal Construction: general. Development of a marine terminal would have impacts similar to those of a permanent service base, except that more extensive shore alterations are usually required. | See B1. | See B1. It should be noted that pipelines would more likely be used than tankers to bring oil to shore in B.C. |
| 5. Marine Terminal Operation: A variety of emissions would result from extensive oil and gas handling, storage and possibly processing facilities. | Cumulative impacts on air quality could be significant in localized areas with poor air circulation. | Potential air pollution problems should be identified in siting a marine terminal. |

TABLE 6.7 (Continued)

| Issue | Significance | Comment |
|---|---|---|
| 6. Marine Terminal Operation: Waste water from terminal operations (run off, bilge and ballast water) could be a source of groundwater, watercourse or harbour pollution. | Chronic small scale sources of water pollution could lead to water quality problems; the overall significance of these problems will depend on the presence of important aquatic habitats. | Gathering and treatment of these wastes will minimize impacts. Ambient pollution levels should be monitored as appropriate. |
| 7. Gas and Oil Storage Facilities: spills, leaks and emissions from tank farms and oil transfer facilities can affect air and water quality in the vicinity of the facility. | Long-term incremental effects could be significant, depending on the characteristics of the site. | Potential pollution problems must be considered in siting these facilities. |
| 9. Ancillary and Induced Facilities: general. The construction and operation of a variety of petroleum-related businesses could have environmental impacts, primarily from development of new industrial sites. | Impacts wil be more significant in communities requiring growth in infrastructure and services to accommodate onshore oil and gas facilities. | Facility-specific and cumulative impacts of ancillary and induced development should be addressed in onshore environmental assessment and planning. |
| 10. Associated Facilities: (e.g., partial processing plant, refinery pipe coating yard). These onshore facilities may develop in association with production from offshore wells. | These facilities have the potential to have significant environmental impacts due to site preparation, waste waters, solid waste production and air emissions. | While individual facilities can be regulated, the cumulative and long-term effects of a variety of oil and gas related activities must be addressed. As with other coastal facilities, careful siting will reduce potential impacts. |

## 6.5 OFFSHORE RISKS AND CONTINGENCY PLANNING

### 6.5.1 OFFSHORE RISKS

The efficient management of offshore exploration and development activities requires that offshore risks be accurately determined and prepared for. This can be accomplished by producing a comprehensive risk analysis to ascertain:

1. the probabilities of oil spills, giving estimated sizes, frequencies, locations and durations;
2. the probabilities of other accidents resulting in pollution or disturbance to the environment;

3. the causes of accidents;
4. the maximum amount of damage possible under worst case conditions and the probabilities of this occurring;
5. the most probable amount of damage that can be expected from:
   a. non-routine events (unforeseen accidents);
   b. routine events (pollution from normal operations).

Information bases which need to be refined or greatly expanded to provide data for a comprehensive risk analysis include:

a. Physical parameters:
   - winds
   - seas
   - currents
   - storm frequencies
   - visibility
   - formation pressures
   - seismicity
   - sediment stability

b. Human parameters:
   - availability and experience of labour
   - capability of workers to function efficiently in west coast environment
   - training standards
   - regulations
c. Resource parameters:
   - estimated size and location of oil and gas reserves
   - production and transport mode estimates

Information derived from the risk analysis will be useful in determining future energy and environmental strategies for British Columbia. Specifically, the analysis will provide the basis for:

a. comparing the risks of offshore development with the risks of future importation of crude oil by deepsea tanker, should internal supplies fail to be replaced by synthetic or alternate fuels;

b. making recommendations on safety zones, regulations, phasing of leasing or drilling operations, pipeline and tanker route locations (these must be coordinated to maximize energy supply, and economic and environmental benefits to British Columbia);

c. assisting the design, engineering, construction and maintenance of offshore equipment, structures, vessels and pipelines.

A comprehensive risk analysis is required in order to develop adequate management plans for offshore development. Table 6.8 illustrates the major components which are required in a risk analysis.

### 6.5.2 CONTINGENCY PLANNING

As a first step in the contingency planning process it will be necessary to determine the existing capabilities and potential opportunities for reducing and eliminating the risks of pollution or other environmental disturbances and/or mitigating any adverse consequences from all phases of offshore petroleum activities. Table 6.9 outlines the major elements which need to be included in a contingency plan.

To accurately forecast potential spill distribution it will be necessary to produce trajectory simulations. These simulations will rely on estimates of weathering rates, effects of dispersants and updated, current studies. The ability of existing technologies to deal with oil spills will also need to be assessed. Long range coastal resource management planning should be coordinated with offshore and onshore contingency planning.

Detailed contingency plans must be developed prior to exploration as well as for each of the later phases of development.

## TABLE 6.8

## MAJOR COMPONENTS OF A RISK ANALYSIS

(adapted from FENCO, 1979: Tables 3.1 and 4.1)

1. Determination of Hazards:
   - a) Product Hazards:
     - Blowouts
     - Spills
     - Fires
     - Explosives
     - Fumes
     - Odours
     - Poison Gas
   - b) Handling Hazards:
     - Litter
     - Noise
     - Venting
     - Sedimentation
     - Discharges
   - c) Structural Hazards:
     - Corrosion
     - Metal Fatigue
     - Faulty Design
     - Collisions
     - Sinkings

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2. Phase Analysis:
   - a) Development:
     - Drilling Platforms
     - Drilling Procedures
     - Subsea Equipment and Techniques
   - b) Operations:
     - Production Platform
     - Separation and Processing
     - Product Transfer
     - Well Servicing
     - Storage and Handling
     - Logistics

## TABLE 6.9

## MAJOR COMPONENTS OF A CONTINGENCY PLAN

1. Introduction - Purpose of Plan
2. Notification System - List of Agencies
3. Priorized List of Response Tasks - Action Outline
4. Designation of Authority - Chain of Command
5. Communications Network - Legal, Public Relations
6. Reference Materials - Sensitivity Maps
7. Trajectory Information - Predictions
8. Equipment Inventory - Type and Location
9. List of Contractors - Local Services, Manpower
10. Dispersants, Disposal Sites
11. References and Appendices

# BIBLIOGRAPHY

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## A PRELIMINARY ENVIRONMENTAL ASSESSMENT OF OFFSHORE HYDROCARBON EXPLORATION AND DEVELOPMENT

### DOCUMENTS (BY AUTHOR)

Adkins, B.E. and A.D. Stefanson. 1979. North Coast Abalone Survey in Harvested Areas. November, 1978. Fish Mar. Ser. M.S. Rep. Ser. No. 1500.

Albers, P.H. 1977. Effects of External Applications of Fuel Oil on Hatchability of Mallard Eggs. In D.A. Wolfe (editor) 1977., Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Environments, Pergamon Press.

Albright, L.J. (advance copy). Heterotrophic Bacterial Biomasses, Activities and Productivities Within the Fraser River Plume, Simon Fraser University.

Allen, A.R. & B.D. Smiley. 1976. Offshore Drilling for Oil in the Beaufort Sea: A Preliminary Environmental Assessment - Technical Report No. 39. Beaufort Sea Project, Environment Canada, Victoria.

Alley, N.F. and B. Thomson. 1978. Aspects of Environmental Geology, Parts of Graham Island, Queen Charlotte Islands. (Bulletin - British Columbia Ministry of the Environment, Resource Analysis Branch, No. 2).

Anderson, J.W. & D.C. Malins. 1978. Summary and Overview: Physiological Stress and Response in Chronically Oiled Organisms. J. Fish. Res. Board Canada 35: 679-680.

Anikouchine, W.A. 1973. The World Ocean: An Introduction to Oceanography. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Anita, N.J., K. Stephens, R.B. Tripp, T.R. Parsons, & J.D.H. Strickland. 1962. A Data Record of Productivity Measurements Made During 1961 and 1962. J. Fish. Res. Board. Canada, M.S. Rep. Ser. (Oceans and Limnol.) No. 35.

Anonymous. 1980. Two Million Dollar Plan to Clear Debris from Fishing Grounds. Offshore Engineer, pp. 85-86.

Arctic Institute of North America. 1980. Ninth Environmental Workshop on Offshore Hydrocarbon Development. Held at Fairmont Hot Springs, B.C. by the University of Calgary, Calgary.

Arctic Institute of North America. 1981. A Decade Ahead: Frontier Oil and Gas Development, 10th Environmental Workshop, April 29-May 1, 1981. Montebello, Quebec. Special publication of the Arctic Institute of North America, University of Calgary.

Arctic Petroleum Operators' Association. 1980. A.P.O.A. Review. Calgary. Austin, W.C., L.D. Druehl, S.B. Haven & J.L. Littlepage. 1971. Marine Benthic Habitats and Biota in the Bamfield area and Zooplankton Survey of Trevor Channel, Barkley Sound. Report No. 2, Bamfield Survey Marine Habitats and Biota.

Baker, R. 1978. A Study of Environmental Concerns: Offshore Oil and Gas Drilling and Production. Policy and Planning Report - Environmental Impact Control Directorate. Fisheries and Environment Canada, Ottawa (EPS-2-EC78-1).

Baker, R.B. Specific Examples of Biological Sciences Requiring Protection. Unpublished Manuscript, Environmental Protection Service, Environment Canada, Ottawa.

Baldwin, P.L. and M.F. Baldwin. 1975. Onshore Planning for Offshore Oil-Lessons from Scotland. The Conservation Foundation, Washington, D.C.

Barkonek, J.C. and D.N. Bettleship (eds.). 1979. Conservation of Marine Birds of Northern North America. Fish and Wildlife Service. U.S.A. Department of the Interior. Wildlife Research Report No. 11. Papers: 1) D.A. Manuwal and R. Wayne Campbell, Status and Distribution of Breeding Seabirds of S.E. Alaska, B.C. and Washington; 2) Munro, W.T. and R.W. Campbell, Programs and Authorities Related to Marine Bird Conservation.

Beaufort Sea Environmental Assessment Panel. 1981. The Beaufort Sea Hydrocarbon Production Proposal - Draft Guidelines for the Preparation of an Environmental Impact Statement. Vancouver, B.C.

Beech, F.G., D.A. Betts and R.L. Sherwood (eds.). 1979. West Coast Oil Spill Countermeasures Study, Year I. Regional Program Report: 79-28. Department of Environment, Environmental Protection Service.

Bell, L.M., and R.J. Kallman. 1976. The Kitimat River Estuary - Status of Environmental Knowledge to 1976. Special Estuary Series No. 6. Report of the Estuary Working Group Department of Environment, Environment Canada.

Bercha, F.G. and Associates Ltd. 1978. Probabilities of Blowouts in Canadian Arctic Waters. Environmental Protection Service (EPS-3-EC-78-12).

Berridge, S.A. 1969. The Formation and Stability of Emulsions of Water in Crude Petroleum and Similar Stocks. J. Inst. Pet. Lond. 54: 333-357.

Bigg, M.A. 1977. Oil Tankers and Marine Mammals in British Columbia. 1) Preliminary Comments. Nanaimo.

Blood, D.A. 1977. Birds and Marine Mammals - The Beaufort Sea and the Search for Oil. Institute of Ocean Sciences, Sidney, B.C.

Borstad, G.A., R.M. Brown, and J.F.R. Gower. 1980a. Airborne Remote Sensing of Sea Surface Chlorophyll and Temperature along the Outer British Columbia Coast. Presented to the 6th Canadian Symposium on Remote Sensing, Halifax, Nova Scotia, May 21-23, 1980.

Borstad, G.A., G.C. Louttit, R.D. Gale, and J.R. Buckley. 1980b. Ships-of-Opportunity Feasibility Study, Part 3. Oceanographic Observation Contractors Report Series 80-2, Institute of Ocean Sciences, Sidney, B.C.

Borstad, G.A., R.M. Brown, D. Truax, T.R. Mulligan and J.F.R. Gower. 1981. Application of Remote Sensing Techniques in Oceanographic Studies of the British Columbia Salmon Fishery. Presented to the 7th Canadian Symposium on Remote Sensing, Winnipeg, Manitoba, September 8-11, 1981.

Brassard, C., D. Harrison, F.A. Kwamena and D. Wright. 1981. Onshore Impacts of Offshore Hydrocarbon Development: An Annotated Bibliography. Prepared for Federal Activities Assessment Branch, Policy Planning and Assessment Directorate, Environment Canada.

Breen, P.A., B.E. Adkins and G.D. Heritage. 1978. Observations of Abalone and Subtidal Communities Made During a Survey of the Queen Charlotte Strait and Upper Johnstone Strait Areas, July 13-20, 1977. Fish. Mar. Serv. Tech. Rep. Ser. No. 789.

Brennan, J.F. and R.P. Meaux. 1964. Observations of the Nearshore Water Circulation off a Sand Beach. U.S. Naval Postgraduate School Thesis, Monterey, California.

Brown, D.W. 1979. Investigation of Petroleum in the Marine Environs of the Strait of Juan de Fuca and Northern Puget Sound. NOAA National Analytical Facility, Environmental Conservation Division, Seattle. (EPA-600/7-79-164).

Brown, J.C. 1978. Oil Spills - Danger in the Sea. Dodd, Mead & Co., New York.

Brownell, R.L. and B.J. LeBoeuf. 1971. California Sea Lion Mortality: Natural or Artifact? In D. Straughan (editor), Biological and Oceanographical Survey of the Santa Barbara Channel Oil Spill, 1969-1970, Volume I. Allan Hancock Foundation, University South California.

Bureau of Land Management. 1979. Final Environmental Statement: Proposed Five-Year OCS Oil and Gas Lease Sale Schedule, United States Department of the Interior.

Bureau of Land Managment. 1981. Norton Sound: Draft Environmental Impact Statement, OCS Proposed Oil and Gas Lease Sale 57. Alaska Outer Continental Shelf Office, U.S. Department of Interior.

Campbell, R.W., H.R. Carter, C.D. Shepard and C.J. Guiguet. 1979. A Bibliography of B.C. Ornithology. Heritage Record No. 7., B.C. Provincial Museum.

Canada. 1976. Oil Spill Countermeasure Map Series. Department of Environment, Environmental Protection Service.

Canada. 1981. Department of Fisheries and Oceans British Columbia Catch Statistics 1976-1980.

CAFSAC. 1981. Consultation on the Consequences of Offshore Oil Production on Offshore Fish Stocks and Fishing Operations. Canadian Atlantic Fisheries Scientific Advisory Committee Research Document. August 1981. Bedford Institute of Oceanography.

Canadian Coast Guard. 1977. Code of Recommended Standards for the Prevention of Pollution in Marine Terminal Systems, Transport Canada.

Canadian Pacific Oceanographic Group, Dixon Entrance, Hecate Strait, Queen Charlotte Sound. 1956. Physical and Chemical Data Record, Pacific Oceanographic Group, Nanaimo, B.C.

Canadian Pacific Oceanographic Group, Hecate Project. 1955. Physical and Chemical Data Record with Appendix I, Current Observation, Nanaimo, B.C.

Cannon, G.A., 1978. Circulation in the Strait of Juan de Fuca. Some Recent Oceanographic Observations. U.S. Department of Commerce, National Oceanic and Atmospheric Administration Technical Report ERL 399-PMEL 29. pp. 1-49. Seattle, Washington.

Carthy, J.D. and D.R. Arthur. 1968. The Biological Effects of Oil Pollution on Littoral Communities. Proceedings from a Symposium at Orielton Field Centre, Pembroke, Wales.

Clark, R.C. and J.S. Finley. 1977. Effects of Oil Spills in Arctic and Sub-Arctic Environments In D.C. Malins (editor), Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms, Volume II, Biological Effects. Academic Press Inc., New York.

Clark, J., J. Zinn and C. Terrell. 1978. Environmental Planning for Offshore Oil and Gas. Volume I: Recovery Technology. The Conservation Foundation, Washington, D.C. U.S. Fish and Wildlife Service, Biological Services Program. (FWS/OBS-77/12).

Clark, J. and C. Terrell. 1978. Environmental Planning for Offshore Oil and Gas. Volume III: Effects on Living Resources and Habitats. The Conservation Foundation, Washington, D.C. U.S. Fish and Wildlife Service, Biological Services Program. (FWS/OBS-77/14)

Coastal Zone Resources Subcommittee. 1978. The Management of Coastal Resources in British Columbia. A Review of Selected Information, prepared for the B.C. Land Resources Steering Committee. Fisheries and Environment Canada.

Colin Karasek Ltd. 1980. Offshore Oil Impact on Harbours and Industrial Lands Eastern Avalon, Prepared for City of St. John's and St. John's Metropolitan Area Board.

Colwell, R.R., A.L. Mills, J.D. Walker, P. Garcia-Tello, and V. Campos-P. 1978. Microbial Ecology Studies of the "Metula" Spill in the Strait of Magellan. J. Fish. Res. Board of Canada. Vol. 35 No. 5.

Cook Inlet. See State of Alaska: Governor's Agency Advisory Committee. 1981.

Coon, L.M., E.J. Field and Canadian Benthic Ltd. 1977. Nootka Sound Kelp Inventory (1975) Marine Resources Branch, Fisheries Management Report No 2.

Coon, L.M., W.G. Roland, E.J. Field and W.L. Clayton. 1979. Kelp Inventory (1976), Part 3. North and West Coast of Graham Island (Q.C.I.) Fisheries Development Report No. 13. Marine Resources Branch, Victoria, B.C.

Coon, L.M., W.G. Roland, E.J. Field, W.L. Clayton and V. Jenson. 1980. Kelp Inventory (1976), Part 4. Goschen Island to the Tree Nob Group. Fisheries Development Report No. 19. Marine Resources Branch, Victoria, B.C.

Coon, L.M. (in prep.). Kelp Inventory (1978) Northwest Coast of Vancouver Island. Fisheries Development Report No. 28. Marine Resources Branch, Victoria, B.C.

Copeland, B.J. 1970. Estuarine Classification and Responses to Disturbances. Transcript American Fisheries Society 28: 1327-1330.

Copeland, B.J. 1970. Estuarine Classification and Responses to Disturbances. Transcript American Fisheries Society 99: 826-835.

Cornwall, G., J. Dalziel, C.J. Edmonds and J. Gerin. 1981. A Canadian Perspective on the Development of North Sea Oil and Gas. Prepared for Environment Canada, Corporate Planning Group.

Craddock, D. R. 1977. Acute Toxic Effects of Petroleum on Arctic and Subarctic Marine Organisms. In D.C. Malins (ed.), Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Volume II, Biological Effects. NOAA, U.S. Dept. of Commerce, Seattle.

Crean, P.B. 1967. Physical Oceanography of Dixon Entrance. Fisheries Research Board of Canada, Ottawa, Ontario.

Cretney, W.A., C.S. Wong, D.R. Green and C.A. Bawden. 1978. Long-term Fate of a Heavy Fuel Oil in a Spill-Contaminated B.C. Coastal Bay. J. Fish. Res. Board of Canada 35. Special Issue - Recovery Potential of Oiled Marine Northern Environments: 521-527.

Curfman, H.J., J.D. Oberholtzer and R.J. Schertler. 1980. Assessment of the Role of Remote Sensing in the Study of Inland and Coastal Waters. National Aeronautics and Space Administration, Scientific and Technical Information Branch. Springfield, Va. 22161

De Malherbe, R. and J.D. Kingham. Risk Analysis in an Integrated Approach to Ecology with Special Reference to the Production and Tranportation of Hydrocarbons. Environment Canada.

Denman, K.L., D.L. Mackas, H.J. Freeland, M.J. Austin and S.H. Hill. 1980. Persistant Upwelling and Mesoscale Zones of High Productivity off the West Coast of Vancouver Island, Canada. In F.A. Richards (editor), I.D.O.E. Symposium on Coastal Upwelling.

Department of Fisheries and Oceans. 1980. An Inventory of Physical Oceanographic Information for the Waters of Queen Charlotte Sound, Hecate Strait, Dixon Entrance, and their Vicinity. Institute of Ocean Sciences, Sidney, B.C.

Department of Fisheries and Oceans, Environmental Assessment Panel. 1978. Guidelines for Preparation of an Environmental Impact Statement for Eastern Arctic Offshore Exploratory Drilling, Vancouver.

Department of Fisheries & Oceans. Spill Technology Newsletter - May-June 1977, March-April 1978, May-June 1978. Environmental Emergency Branch, Environmental Protection Service, Ottawa.

Department of Fisheries and Oceans, Working Group on the East Coast Deep Water Oil Ports. 1976. An Environmental Risk Index for the Siting of Deep Water Oil Ports. Ottawa.

Dilke, B.R., S. McKinnell, and R.I. Perry. 1979. M.V. Imperial Tofino Ships of Opportunity Program March 1978-March 1979. University of British Columbia, Dept. of Oceanography, Vancouver.

Dirschl, H.J. 1980. The Lancaster Sound Region: B1980-2000, Perspectives and Issues on Resource Use. (Draft Green paper). Indian and Northern Affairs Canada, Ottawa.

Dodimead, A.J. 1980. General Review of the Oceanography of the Queen Charlotte Sound - Hecate Strait - Dixon Entrance Region. Department of Fisheries & Oceans, Nanaimo, B.C.

Dodimead, A.J. 1965. Oceanographic Atlas of the Subarctic Pacific Region, Summer 1961. Pacific Oceanographic Group, Nanaimo, B.C.

Dodimead A.J. and Favorite. 1961. Oceanographic Atlas of the Pacific Subarctic Region, Summer 1958. Pacific Oceanographic Group, Nanaimo, B.C.

Dome Petroleum Limited. 1981. Environmental Setting and Assessment for a Liquefied Natural Gas Terminal at Grassy Point, Port Simpson Bay, Northern British Columbia. Volume 3.

Draper, D. 1980. Coastal Zone Management: Opportunities and Necessities for Newfoundland. In Proceedings of a workshop on Environmental Considerations of East Coast Offshore Hydrocarbon Development.

Eastcoast Petroleum Operators Association. Eastern Offshore News. Volume 1, Numbers 1,2,3 (1979); Volume 2, No. 1 (1980); Volume 3, No. 1 (1981). Calgary, Alberta.

East-West Centre. 1982. Environmental Planning Guidelines for Offshore Oil and Gas Development.

Ellers, F.S. 1982. "Advanced Offshore Oil Platforms". Scientific American, Vol. 246, No. 4.

Environment and Land Use Committee Secretariat. 1978. Analysis of Tanker-Casualty Spill Risk Arising from West Coast Oil Port Proposals.

Environment and Land Use Committee Secretariat. 1979. South Moresby Island Wilderness Proposal. An Overview Study, Victoria, B.C.

Environment Canada: Environmental Protection Service. 1975. The Effectiveness and Toxicity of the Oil Dispersant, Oilsperse 43, In Large Outdoor Tanks. (EPS 5-AR-75-8).

Environment Canada: Environmental Protection Service. 1978. West Coast Offshore Environment: Maps 1-9.

Environment Canada: Environmental Protection Service. 1979. West Coast Oil Spill Countermeasures Study, Year I. Regional Program Report: 79-28. Beech, F.G. et al.

Environment Canada 1980. Proceedings of Offshore Environment in the 1980's. St. John's, Newfoundland.

Environmental Assessment and Review Panel. 1976. Guidelines for Preparing Initial Environmental Evaluations. Vancouver, B.C.

Environmental Assessment Panel. 1980. Guidelines for the Preparation of an Environmental Impact Statement for Potential Oil Production on the Northeast Grand Bank. Ottawa, Ontario.

Environmental Conservation Directorate. 1976. Field Evaluation of Seven Oil Spill Recovery Devices. Environment Canada, Environmental Protection Service. (Technology Development Report, EPS-4-EC-76-3).

Environmental Conservation Directorate. 1976. Spill in Portugal, A Report of the JAKOB MAERSK Incident. Environment Canada, Environmental Protection Service. (Environment Impact and Assessment Report, EPS-8-EC-76-2).

Environmental Conservation Directorate. 1976. The Mizushima Oil Spill - A Tragedy for Japan and a Lesson for Canada. Environment Canada, Environmental Protection Service.

Environmental Impact Control Directorate. 1980. A Selected Bibliography on the Fate and Effects of Oil Pollution Relevant to the Canadian Marine Environment. Environment Canada, Environmental Protection Service.

Environmental Protection Agency, U.S. Department of Commerce. 1979. Food Web Relationships of Northern Puget Sound and the Strait of Juan de Fuca - A synthesis of the Available Knowledge.

Environmental Services Unit, Land Management Branch. 1977. The Environmental Implications of Oil Tanker Traffic on the British Columbia Coast. Ministry of Environment, Victoria. B.C.

Evans, D.R. and S.D. Rice. 1973. Effects of Oil on Marine Ecosystems: A Review for Administrators and Policy Makers. Fisheries Bulletin: (72), No. 3.

Exxon Corporation - The Public Affairs Department. 1978. The Offshore Search for Oil and Gas. Exxon Background Series. Third Edition.

FAO. 1977. Impacts of Oil on the Marine Environment. Food and Agriculture Organization, Rome.

Federal Environmental Assessment Review Office. 1978. Guidelines for Preparation of an Environmental Impact Statement for Eastern Arctic Offshore Exploratory Drilling. Department of Fisheries and Environment Canada.

Federal Environmental Assessment Review Office. Report of the Environmental Assessment Panel: Volume 6 - Eastern Arctic Offshore Drilling - South Davis Strait Project, 1978; Volume 7 - Lancaster Sound Drilling, 1979.

Fenco Consultants Ltd. 1979. Sources of Pollution and Causes of Environmental Disturbance Associated with Canadian Offshore Oil and Gas Production. Prepared for Environmental Protection Service, Environment Canada, Edmonton.

Forrester, W.D. 1971. Distributions of Suspended Oil Particles Following the Grounding of the Tanker Arrow. J. Mar. Res. 29: 151-170.

Fingas, M.F., W.S. Duval and G.B. Stevenson. 1979. The Basics of Oil Spill Cleanup With Particular Reference to Southern Canada. Environment Canada, Minister of Supply & Services, Hull, Quebec.

Fisheries and Environment Canada. 1978a. A Study of Environmental Concerns: Offshore Oil and Gas Drilling and Production. Ottawa.

Fisheries and Environment Canada. Feb. 1978b. Potential Pacific Coast Oil Ports: A Comparative Environmental Risk Analysis, Vols. I and II. Prepared by Fisheries and Environment Canada Working Group on West Coast Deepwater Oil Ports.

Fralick, J.E. & D.L. Tillapaugh. 1979. A Review of Smaller Fishery-Mariculture Industries in B.C.: Mussels, Abalone Geoducks, Clams, Horse Clams and Marine Plants. Westwater Research Centre Information Report No. 3.

French, R.H., H. Bilton, M. Osako, & A. Hartt. 1976. Distribution and Origin of Sockeye Salmon (Oncorhynchus nerka) in Offshore Waters of the North Pacific Ocean. Int. N. Pac. Fish. Comm. Bull. 34.

Gamble, D.J. 1981. Improving the Decision-Making Process. Prepared for workshop on "Frontier Oil & Gas Development: The Decade Ahead", Ottawa.

Geraci, J.R. and D.J. St. Aubin. 1980. Offshore Petroleum Resource Development and Marine Mammals: A Review and Research Recommendations. Marine Fisheries Review, N.O.A.A. National Marine Fisheries Service.

Gilbert, J. (Ed). 1982. Environmental Planning Guidelines for Offshore Oil and Gas Development. East-West Center Book, University Press of Hawaii.

Gilfillan, E.S. and J.H. Vandermeulen. 1978. Alterations in Growth and Physiology in Softshell Clams, Mya arenaria, Chronically Oiled with Bunker C from Chedabucto Bay, Nova Scotia, 1970-76, J. Fish. Res. Board of Canada. 35: 630-636.

Godfrey, H., K.A. Henry and S. Machidori. 1975. Distribution and Abundance of Coho Salmon in Offshore Waters of the North Pacific Ocean. Int. N. Pac. Fish. Comm., Bull. 31.

Gordon, D., W. Duval and R. Olmsted. 1977. An Assessment of the Implications to Northern British Columbia Fisheries Resources of Tanker Operations Associated with the Proposed Kitimat Pipe Line Limited Development. Prepared for Kitimat Pipe Line Ltd., Vancouver.

Green, D.R., C. Bawden, W.J. Cretney and C.S. Wong. 1974. The Alert Bay Oil Spill: A One Year Study of the Recovery of a Contaminated Bay. Unpublished Manuscript, Marine Sciences Directorate, Pacific Region, Pacific Marine Science Report 7409.

Gulf Oil Canada Limited. 1974. B.C. Area - Oil Spill Action Plan.

Haegele, C.W. and M.J. Hamey. 1977. Shoreline Vegetation Maps of Some Major Herring Spawning Localities on the West Coast of Vancouver Island: Nuchalitz, Nootka Sound, Hesquiat Harbour and Barkley Sound. Fish. Mar. Serv. M.S. Rep. No. 1430.

Haegele, C.W. and M.J. Hamey. 1979a. Shoreline Vegetation on Herring Spawning Grounds in Clayoquot Sound. Fish. Mar. Serv. M.S. Rep. No. 1536.

Haegele, C.W. and M.J. Hamey. 1979b. Shoreline Vegetation on Herring Spawning Grounds in Stuart Channel, Strait of Georgia, B.C. Fish. Mar. Serv. M.S. Rep. No. 1534.

Haegele, C.W. and M.J. Hamey. 1980. Shoreline Vegetation on Herring Spawning Grounds in Barkley Sound in 1978 Compared with Similar Assessments for 1974 and 1975. Fish. Mar. Serv. M.S. Rep. No. 1549.

Haimila, N.E. and R.M. Procter. 1981. Hydrocarbon Potential of Offshore British Columbia. Geological Survey of Canada, Dept. of Energy, Mines and Resources, Calgary. Draft Copy.

Hanna, B.M., J.A. Hellebust, T.C. Hutchinson, 1974. Field Studies on The Phytotoxicity of Crude Oil to Subarctic Aquatic Vegetation. Institute for Environmental Studies, University of Toronto. XIX SIL Congress, Winnipeg.

Harper, J.R. 1980. Coastal Processes on Graham Island, Queen Charlotte Islands, British Columbia. In Current Research, Part A, Geological Survey of Canada, Paper 80-1A, pp. 13-18.

Harrald, J.R. B.D. Boyd and C. Bates. 1977. Oil spills in the Alaskan Coastal Zone: the Statistical Picture. In D. Wolfe (ed.) Facts and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. Pergamon Press, Toronto.

Hart, J.L. 1973. Pacific Fishes of Canada. Fish. Res. Board. Canada Bull. 173.

Hartung, R. 1965. Some Effects of Oiling on Reproduction of Ducks. Journal of Wildlife Management. 29.

Hartung, R. and G.S. Hunt. 1966. Toxicity of Some Oils to Waterfowl. Journal of Wildlife Management. 30: 564-570.

Hawkes, M.W., C.E. Tanner, and P.A. Lebednik. 1978. The Benthic Algae on Northern B.C. Syesis 11: 81-115.

Herlinveaux, R.N. 1972. Preliminary Report on the Oil Spill from the Freighter "Vanlene". Marine Sciences Directorate, Victoria, B.C.

Ho, D.S.N. 1978. The Marine Receiving Water Monitoring Program for Pulp Mill Effluent at Prince Rupert. From preprints of papers presented at the 1978 Spring Conference, Canadian Pulp and Paper Association, Technical Section - Pacific Coast and Western Branches. May 17-21, 1978. Jasper, Alberta.

Holbrook, J.R., R.D. Muench, D.G. Kachel and C. Wright, 1980. Circulation in the Strait of Juan de Fuca: Recent Observations in the Eastern Basin. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Technical Report ERL 412-PMEL 33. pp. 1-42. Seattle, Washington.

Holmes, W.N. and J. Cronshaw. 1977. Biological Effects on Marine Birds. In D.C. Malins (editor). Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms, Volume II. Biological Effects. Academic Press Inc., New York.

Hoos, L.M. 1975. The Skeena River Estuary - Status of Environmental Knowledge to 1975. Special Estuary Series No. 3. Environment Canada.

Hourston, A.S. and C.W. Haegle. 1980. Herring on Canada's Pacific Coast. Can. Spec. Publ. Fish. Aquatic Sci. 48.

Hyland, J.L. and E.D. Schneider. 1976. Petroleum Hydrocarbons and Their Effects on Marine Organisms, Populations, Communities, and Ecosystems. In Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. Proceedings of Symposium. American Institute of Biological Sciences.

International Conference on Oil Pollution of the Sea; at Rome. 1968. Sponsored by: British Advisory Committee on Oil Pollution of the Sea, Italian National Committee on Oil Pollution of the Sea, Nordic Union for the Prevention of Oil Pollution of the Sea.

International Tanker Owners Pollution Federation Ltd. 1980. Measures to Combat Oil Pollution - the Improvement of Oil Spill Response Within the European Economic Community for the Commission of the European Communities. Graham and Trotman Ltd., London, England.

Jackson, J.B. and R.T. Durrier. 1980. OCS Oil and Gas Activities in the Gulf of Alaska (including Lower Cook Inlet) and their Onshore Impacts: A Summary Report. Prepared for the U.S. Department of the Interior, Geological Survey. Rogers, Golden and Halpern, Inc. Philadelphia (U.S.G.S. Open-File Report 80-1028).

Johnson, F.G. 1977. Sublethal Biological Effects of Petroleum Hydrocarbon Exposures: Bacteria, Algae and Invertebrates. In D.C. Malins (ed.), Effects of Petroleum on Arctic and Subarctic marine Environments and Organisms. Volume II. Biological Effects. Academic Press Inc., New York.

Johnston, R. 1970. The Decomposition of Crude Oil Residues in Sand Columns. Journal of the Marine Biology Association U.K. Vol. 50.

Kennedy, J.L. Losing Control While Drilling: A 32 Well Look at Causes and Results. Oil and Gas Journal, September 20, 1971.

Kiltau, D.K. and J.J.M. Oude Hengel. Protection of North Sea Pipelines from Trawl Gear Evaluated in Program. Oil and Gas Journal, June 1981.

Kooyman, G.L., R.W. Davis and M.A. Castellini. 1977. Thermal Conductance of Immersed Pinniped and Sea Otter Pelts Before and After Oiling with Prudhoe Bay Crude. In D.A. Wolfe (editor), Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press, Oxford.

Kozloff, E.N. 1973. Seashore Life of Puget Sound, the Strait of Georgia and the San Juan Archipelago. J.J. Douglas Ltd., Vancouver, B.C.

Kramer, L.S., V.C. Clark, and G.J. Cannelos. 1978. Planning for Offshore Oil Development: Gulf of Alaska OCS Handbook. Alaska Department of Community and Regional Affairs, Juneau, Alaska.

Kuhnhold, W.W. 1972. The Influence of Crude Oils on Fish Fry. In Mario Ruivo (ed.), Marine Pollution and Sea Life, F.A.O. London.

Lands and Housing Regional Operations Division, Skeena Region. 1980. Graham Island Crown Land Plan. B.C. Ministry of Lands, Parks, and Housing.

Le Beouf, B.J. 1971. Oil Contamination and Elephant Seal Mortality: A Negative Finding. In Biological and Oceanographic Survey of the Santa Barbara Channel Oil Spill, 1969-1970. Volume I. In D. Straughan (ed.), Allan Hancock Foundation, University of Southern California.

Le Brasseur, R.J. 1965a. Biomass Atlas of Net Zooplankton in the Northeastern Pacific Ocean 1955-1964. J. Fish. Res. Board of Canada. M.S. Rep. Ser. No. 201.

Le Brasseur, R.J. 1965b. Seasonal and Annual Variations of Net Zooplankton at Ocean Station P. 1956-1964. J. Fish. Res. Board of Canada. M.S. Rep. No. 202.

Lee, J.C. and N. Bourne. 1977. Marine Resource Inventory of Pacific Rim National Park -1976. Fish. and Mar. Ser. M.S. Rep. No. 1436.

Logan, W.J., D.E. Thornton, and S.L. Ross. 1975. Oil Spill Countermeasures for the Beaufort Sea. Department of the Environment, Victoria.

Longley, W.L., R. Jackson and B. Snyder. 1978. Managing Oil and Gas Activities in Coastal Environments. U.S. Fish and Wildlife Service, Biological Services Program. (FWS/OBS-78/54).

Lusk, B.M. 1978. Shore Based Surveys, Pacific Region. Canadian Hydrographic Survey, Sidney. B.C.

MacDonald, R.W., Institute of Ocean Sciences. An Examination of Metal Inputs to the Southern Beaufort Sea by Disposal of Waste Barite in Drilling Fluids. Unpublished paper.

Machemehl, J.L. 1979. Pipelines in the Coastal Ocean. Proceedings of the A.S.C.E., Pipeline Division, June 15, 1979.

Mackay, D. 1981. Fate and Behavior of Oil Spills. Institute for Environmental Studies, University of Toronto, Toronto.

Mackay, S.P., G.T. Glazier and I.R. Smyth. 1981. Major Frontier Project Approvals: Industry Review. Prepared for workshop on "Frontier Oil & Gas Development - The Decade Ahead", Montebello, Quebec.

MacKnight, S.D., P. Keizer, M. Gagnon and R. Leblanc. 1981. Grand Banks Oceanographic Studies. Prepared by McLaren Plansearch Ltd. for Mobil Oil of Canada Ltd. Final Report, Vol. 4, Sect. 8.

MacLaren Plansearch Lavalin. 1982. Environmental Management of Offshore Development Report for Province of British Columbia. Ministry of Environment, Assessment Branch.

MacLaren, J.F. Ltd. 1980. Report on Meetings on Environmental Concerns Related to Offshore Oil and Gas Drilling and Production. Volumes I and II. Organized for Environment Canada and Supply and Services Canada.

Malins, D.C. 1977. Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms. Volume I - Nature and Fate of Petroleum, Volume II -Biological Effects. NOAA, U.S. Department of Commerce, Academic Press Inc., Seattle.

Manuwal, D.A., T.R. Wahl, and S.M. Speich. 1979. The Seasonal Distribution and Abundance of Marine Bird Populations in the Strait of Juan de Fuca and Northern Puget Sound in 1978. NOAA Technical Memo. ERL MESA - 44.

Mason, J.C., O.D. Kennedy and T.H. Mullin. 1981. Canadian Pacific Coast Ichthyoplankton Survey 1980. Hydrography; Parts One, Two, and Three. Canadian Data Report of Fisheries and Aquatic Sciences Nos. 279, 280, and 281.

Mason, J.C., O.D. Kennedy and A.C. Phillips. 1981. Canadian Pacific Coast Ichthyoplankton Survey 1980. Ichthyoplankton. Cruise One through Cruise Four. Canadian Data Report of Fisheries and Aquatic Sciences No. 275-278.

Mathews, W.H. 1958. Underwater Gravel Deposits of Dixon Entrance. Institute of Oceanography, University of British Columbia, Vancouver.

McAllister, C.D. 1962. Measurements of Primary Production at Ocean Station P. J. Fish. Res. Board of Canada. M.S. Rep. Ser. No. 137.

McAllister, C.D., T.R. Parsons and J.D.H. Strickland. 1959. Data Record, Ocean Fertility and Productivity Measurements at Ocean Station P. J. Fish. Res. Board of Canada. M.S. Rep. No. 55.

McDonald, J.W. and T. Jandali. 1980. Physical/Chemcial Oceanography Inventory West Coast British Columbia. Prepared for Trans Mountain Pipe Line Co. Ltd., Vancouver, B.C. Vol. XV, Parts A and B.

McEwan, E.H., N. Aitchison and P.E. Whitehead. 1974. Energy Metabolism of Oiled Muskrats, Canadian J. Zoology Vol. 52.

McKelvey, R.W. 1976. Fall Aerial Survey of Marine Birds and Mammals off the British Columbia Coast. Canadian Wildlife Service, Delta, B.C.

McPhee, M.N. 1982. Offshore Oil in Canada: Westcoast Environmental, Social and Economic Impacts. Westwater Research Centre, University of British Columbia, Vancouver, B.C.

McQuiune, R. and D.A. Ardus. 1977. Exploring the Geology of Shelf-Seas. Graham and Trotman Ltd., London, England.

Mertens, E.W. 1976. The Impact of Oil on Marine Life: A Summary of Studies. In Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. Symposium Proceedings, American Institute of Biological Sciences.

Michael, A.D. 1977. The Effects of Petroleum Hydrocarbons on Marine Populations and Communities. In D.A. Wolfe (editor), Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems, Pergamon Press.

Miller, B.A., C.A. Simenstad, J.N. Cross, K.L. French and S.N. Steinfort. 1980. Nearshore Fish and Microinvertebrate Assemblages Along the Strait of Juan de Fuca Including Food Habitats of the Common Nearshore Fish. MESA Puget Sould Project. U.S. EPA.

Milne, A.R. and B.D. Smiley. 1976. Offshore Drilling for Oil in the Beaufort Sea: A Preliminary Environmental Assessment. Technical Report No. 39. Beaufort Sea Project, Department of the Environment, Victoria.

Milne, A.R. 1977. Oil, Ice and Climate Change - The Beaufort Sea and the Search for Oil. Institute of Ocean Sciences, Sidney, B.C.

Milne, A.R. and R.H. Herlinveaux. 1977. Crude Oil in Cold Water - The Beaufort Sea and the Search for Oil. Institute of Ocean Sciences, Sidney, B.C.

Milne, W.G., G.C. Rogers, R.P. Riddihough, G.A. McMechan and R.D. Hybdnan. 1978. Seismicity of Western Canada. Can. J. Earth Sci. Vol. 15.

Ministry of Environment, Fish and Wildlife Branch. 1977. Northern B.C. Coastal Wildlife Resources Map.

Ministry of Indian Affairs and Northern Development. 1981. E.A.M.E.S. - The Achievements of an Environmental Program, Ottawa.

Mironov, O.G. 1967. Effects of Low Concentrations of Oil and Oil Products on the Developing Eggs of the Black Sea Flatfish. Vop. Ikhtiol., Vol. 7(3).

Mironov, O.G. 1972. Effect of Oil Pollution on Fauna and Flora of the Black Sea. In Mario Ruvio (ed.). Marine Pollution and Sea Life. F.A.O. London.

Mitchell, J.K. Impact of Offshore Oil and Gas Development on the Coastal Zone: Reforming the Environmental Impact Assessment Process. In Marc Hershman (ed.) Coastal Zone Management Journal Vol. (4)3.

Mitre Corp. 1979. Outer Continental Shelf Environmental Monitoring Concerns. Prepared for Council on Environmental Quality, U.S. Department of Commerce, Washington, D.C. (NTIS PB-299 861).

Moles, A., S.D. Rice and S. Korn. 1979. Sensitivity of Alaskan Freshwater and Anadromous Fishes to Prudhoe Bay Crude Oil and Bengene. Trans. Amer. Fish. Soc. Vol. 108.

Moore, S.F. 1973. Towards a Model of the Effects of Oil on Marine Organisms. In Background Information for Ocean Affairs Board Workshop on Inputs, Fates and Effects of Petroleum in the Marine Environment, Airlie, Va.; cited in Hyland J.L., and Eric A. Schneider.

Morris, S. and A. Leany. 1980. The Somass River Estuary - Status of Environmental Knowledge to 1980. Special Estuary Series No. 9. Environment Canada.

Morrow, J. 1973. Oil Induced Mortalities in Juvenile Coho and Sockeye Salmon. J. Mar. Res. Vol. 31.

Mostert, N. 1974. Supership. Alfred A. Knopf, New York, N.Y.

National Academy of Sciences. 1975. Petroleum in the Marine Environment. Washington, D.C.

Neave, F. 1964. Ocean Migrations of Pacific Salmon. J. Fish Res. Board of Canada. Vol. 21(5).

Neave, F. and R.G. Bakkala. 1976. Distribution and Origin of Chum Salmon in Offshore Waters of the North Pacific Ocean. Int. N. Pac. Fish. Comm. Bull. 35.

Neff, J. M., J.W. Anderson, B.A. Cox, R.B. Laughlin Jr., S.S. Rossi and H.E. Tatem. 1976. Effects of Petroleum on Survival, Respiration and Growth of Marine Animals. In Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. Symposium Proceedings, American Institute of Biological Sciences.

Neff, J. M., R.S. Carr and W.L. McCulloch. 1981. Acute Toxicity of a Used Chrome Lignosulphonate Drilling Mud to Several Species of Marine Invertebrates. Marine Environmental Research. Vol. 4.

Neilson, L.N. 1981. Shrimp and Prawns: Potential Subjects for Mariculture in British Columbia. Province of British Columbia. Marine Resources Branch. Information Report No. 2.

Nelson, J.G. 1977. Displacement of Yukon - Derived Sediment from Bering Sea to Chukchi Sea during Holocene Time. Geology. Vol. 5.

Nelson, J.G. and S. Jessen. 1981. The Scottish and Alaskan Offshore Oil and Gas Experience and the Canadian Beaufort Sea. Canadian Arctic Resources Committee, Ottawa and University of Waterloo, Waterloo.

Nelson-Smith, A. 1968. The Effects of Oil Pollution and Emulsifier Cleansing on Marine Life in Southwest Britain. J. Applied Ecol. Vol. 5.

Nelson-Smith, A. 1972a. Effects of the Oil Industry on Shore Life in Estuaries. Proc. R. Soc. Lond. B. Vol. 180.

Nelson-Smith, A. 1972b. Oil Pollution and Marine Ecology. Paul Elek (Scientific Books) Ltd., London.

New England River Basins Commission - Resource and Land Investigations: (NERBC-RALI) 1978. Onshore Facilities Related to Offshore Oil and Gas Development. Volume 1 Factbook, Volume 3 Methodologies for OCS-Related Facilities Planning. NERBC-RALI, Boston.

Newfoundland Department of Development. 1981. Site Locations for Onshore Petroleum Related Developments: Preliminary Analysis of Sites.

Norton Sound: Draft Environmental Impact Statement. U.S. Department of the Interior, Bureau of Land Management. June 1981.

Nova Scotia Department of Mines and Energy. 1980. Offshore Oil and Gas: A Chance for Nova Scotians.

Oakley, K.A. 1981. Consultation Process and Related Matters, Oil Industry/Fisheries. Prepared for Nova Scotia Voluntary Planning, Fishery Sector Committee, St. John's, Newfoundland.

Office of State Planning, Commonwealth of Massachusetts. 1976. Offshore Oil Development - Implications for Massachusetts Communities. Office of Coastal Zone Management.

Ohlendorf, H.M., R.W. Risebrough, and Kees Vermeer. 1978. Exposure of Marine Birds to Environmental Pollutants. Fish and Wildlife Service, U.S. Department of the Interior. Wildlife Research Report No. 9.

Oil Spill Intelligence Report. Jan., March and June, 1982. Center for Short-Lived Phenomena. Cambridge, Maryland and Cahners Publishing Company, Boston, Massachusetts.

Owens, E.H., John A. Leslie and Associates. 1977. Coastal Environments of Canada: The Impact and Cleanup of Oil Spills. Department of Fisheries and Environment.

Owens, E.H. 1978. Mechanical Dispersal of Oil Stranded in the Littoral Zone. J. Fish. Res. Board Canada 35. Special Issue - Recovery Potential of Oil Marine Northern Environments.

Paish, H. and Associates Ltd. 1972. The West Coast Oil Threat in Perspective: Volume II Main Report, prepared for Environment Canada.

Parker, R.R. 1971. Size Selective Predation Among Juvenile Salmonid Fishes in a British Columbia Inlet. J. Fish. Res. Board of Canada. Vol. 28.

Parsons, T.R. 1965. A General Description of Some Factors Governing Primary Production in the Strait of Georgia, Hecate Strait and Queen Charlotte Sound. J. Fish. Res. Board of Canada. M.S. Rep. Ser. (Oceans and Limnol) No. 193

Parsons, T.R., M., Tagahashi and B. Hargrave. 1977. Biological Oceanographic Processes. Pergamon Press, Oxford.

Patten, B.G. 1977. Sublethal Biological Effects of Petroleum Hydrocarbon Exposures: Fish. In Donald C. Malins (ed.), Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms, Volume II. Biological Effects. Academic Press Inc. Seattle.

Peakall, D.B., J. Tremblay, W.B. Kinter and D.S. Miller. 1981. Endocrine Dysfunction in Seabirds caused by Ingested Oil. Environmental Research Vol. 24.

Penrose, W.R. 1981. Effects of Hydrocarbons and Dispersants on Fish. In J.B. Sprague, J.H. Vandermeulen and P.G. Wells (eds.) Oil and Dispersants in Canadian Seas - Research Appraisal and Recommendations. A report prepared for the Environmental Protection Service, Environment Canada. Advance Copy.

Percy, J.A. 1981. Benthic and Intertidal Organisms. In J.B. Sprague, J.H. Vandermeulen and P.G. Wells (eds.), Oil and Dispersants in Canadian Seas - Research Appraisal and Recommendations. A report prepared for the Environmental Protection Service, Environment Canada. Advance Copy.

Perry, R.I., B.R. Dilke, G.C., Louttit, and S. McKinnell. 1981. M.V. Imperial Tofino Ships of Opportunity Program. May 1979-June 1980. University of British Columbia, Dept. of Oceanography, Vancouver.

Petro Canada 1981. Grand Banks Environmental Overview. Vol. I.

Petroleum Directorate, Economics Unit. 1981. Effects of the Federal Energy Policy on Oil & Gas Exploration and Production Offshore Newfoundland and Labrador. Government of Newfoundland and Labrador publication. Special Report PD 81-1.

Proceedings of Third Annual Conference: Energy Across the Coastal Zone, November 3-5, 1977, Seattle, Washington. The Coastal Society, Arlington, Virginia.

Province of British Columbia. 1981. Submission of the Province of British Columbia on West Coast Maritime Boundaries between Canada and the United States. Ministry of Intergovernmental Relations, Victoria, B.C.

Rice, S.D. 1973. Toxicity and Avoidance Tests with Prudhoe Bay Crude Oil and Pink Salmon Fry. In Proc. of Joint Conf. on Rev. and Cont. of Oil Spills. American Petroleum Institute, E.P.A., U.S. Coast Guard.

Rice, S.D., D.A. Moles and J. Short. 1975. The Effect of Prudhoe Bay Crude Oil on Survival and Growth of Eggs Alevins and Fry of Pink Salmon Oncorhynchus gorbushca. In Proceedings, 1975 Conference on Prevention and Control of Oil Pollution. American Petroleum Institute, E.P.A.

Rice, S.D., J.W. Short and J.F. Karinen. 1976. Toxicity of Cook Inlet Crude Oil and No. 2 Fuel Oil to Several Alaskan Marine Fishes and Invertebrates. In Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. Symposium Proceedings, American Institute of Biological Sciences.

Ricketts, E.F. and J. Calvin. 1968. Between Pacific Tides. Revised by Joel W. Hodgepeth. Stanford University Press, Standford, Calif.

Robbins, Capt. C.E. June 6-8, 1977. Maritime Traffic Management, Its Weakness, Its Future. In Proceedings of the 1977 Tanker Conference (Woodlands, Texas, U.S.A.)

Rogers, G.C. 1982. Revised Seismicity and Revised Fault Plane Solutions for the Queen Charlotte Islands Region. Open File No. 82-83 Ottawa.

Ross, S.L., W.J. Logan and W. Roland. 1977. Oil Spill Countermeasures - The Beaufort Sea and the Search for Oil. Department of Fisheries and the Environment, Ottawa.

Samson, A.L., J.H. Vandermeulen, P.G. Wells and C. Moyse (compilers). 1980. A Selected Bibliography on the Fate and Effects of Oil Pollution Relevant to the Canadian Marine Environment. Environmental Protection Service, Environment Canada (Report No. EPS 3-EC-80-5).

Sanborn, H.R. 1977. Effects of Petroleum on Ecosystems. In D.C. Malins (ed.) Effects of Petroleum on Arctic and Subarctic Marine Environments and Organisms, Volume II. Biological Effects. Academic Press Inc. New York.

Savard, Jean-Pierre. 1979. Marine Birds of Dixon Entrance, Hecate Strait and Chatham Sound, B.C. (Conducted during Fall 1977 and Winter 1978). Canadian Wildlife Service, Delta, B.C.

Scarratt, D.J. 1981. Consequences of Offshore Oil Production on Fish Stocks and Fishing Operations. Spill Technology Newsletter, Environmental Protection Service, Environment Canada. January - February.

Scarratt, D.J. and V. Zitko. 1972. Bunker Oil in Sediments and Benthic Animals from Shallow Depths in Chedabucto Bay, N.S. J. Fish. Res. Board of Can. Vol. 29.

Seabird Colonies of Vancouver Island, B.C. Provincial Museum.

Seabird Colonies of the Queen Charlotte Islands. 1979. B.C. Provincial Museum.

Sedco Incorporated. 1976. Sedco 706 Marine Operations Manual. For Mobile Offshore Drilling Units. San Francisco.

Sewell, D. and H.D. Foster. 1981. An Assessment of Canadian Environmental Policies on Offshore Development. Prepared for Policy Directorate, Corporate Planning Group, Environment Canada, University of Victoria, Victoria, B.C.

Slaney, F.F. and Co. Ltd. 1977. An Assessment of the Implications to Northern British Columbia Fisheries Resources of Tanker Operations Associated with the Proposed Kitimat Pipe Line Limited Development. Prepared for Kitimat Pipe Line Ltd., Vancouver, B.C.

Slater, J. 1978. Shore Protection Analysis - An Inventory of the Marine Shore Resources of Saanich with Shoreland Management and Protection Recommendations. Staff Environment Group. The Corporation of the District of Saanich.

Smiley, B.D. The Effects of Oil on Marine Mammals. In J.B. Sprague, J.H. Vandermeulen & P.G. Wells (eds.) Oil and Dispersants in Canadian Seas - Research Appraisal and Recommendations. A report prepared for the Environmental Protection Service. Environment Canada (Advance Copy).

Smith, J.E. (ed.). 1968. Torrey Canyon Pollution and Marine Life, A Report by the Plymouth Laboratory of the Marine Biological Association of the United Kingdom. University Press, Cambridge.

Snow, N. 1981. Effects of Petroleum Hydrocarbons on Phytoplankton and Macrophytes. In J.B. Sprague, J.H. Vandermeulen and P.G. Wells (eds.) Oil and Dispersants in Canadian Seas - Research Appraisal and Recommendations. A report prepared for the Environemntal Protection Service, Environment Canada (Advance Copy).

Southward, A.J. and E.C. Southward. 1978. Recolonization of Rocky Shores in Cornwall After Use of Toxic Dispersants to Clean Up the Torrey Canyon Spill. J. Fish. Res. Board of Canada 35. Special Issue - Recovery Potential of Oiled Marine Northern Environments.

Sowls, A.L., S.A. Hatch, and C.J. Lensik. 1978. Catalogue of Alaskan Sea Bird Colonies. Fish and Wildlife Service. U.S. Department of the Interior.

Sprague, J.B., J.H. Vandermeulen, P.G. Wells (eds.) 1981. Oil and Dispersants In Canadian Seas - Research Appraisals and Recommendations. Prepared for Environmental Emergency Branch, Environmental Impact Control Directorate. Environmental Protection Service, Environment Canada.

State of Alaska: Governor's Agency Advisory Committee. 1981. A Social, Economic and Environmental Analysis of a State Oil and Gas Lease Sale in Lower Cook Inlet (Preliminary Draft).

Stegemen, J.J., and D.J. Sabo. 1976. Aspects of the Effects of Petroleum Hydrocarbons on Intermediary Metabolism and Xenobiotic Metabolism in Marine Fish. In Sources, Effects and Sinks of Hydrocarbons in the Aquatic Environment. Proceedings of Symposium.

Stegemen, J.J. 1978. Influence of Environmental Contamination on Cytochrome Mixed-Function Oxygenases in Fish: Implications for Recovery in the Weld Harbour Marsh. J. Fish. Res. Board Canada 35. Special Issue -Recovery Potential of Oiled Marine Northern Environments.

Steinhart J. and C. Steinhart. 1971. Blowout - A Case Study of the Santa Barbara Oil Spill. Duxbury Press, University of Wisconsin.

Stephens, K. 1964. Data Record Productivity Measurements in the Northeast Pacific with Associated Chemical and Physical Data 1958-1964. J. Fish. Res. Board Canada. Rep. Ser. (Oceanographic and Limnol.) No. 179.

Stephenson, I.A. and A. Stephenson. 1972. Life Between Tidemarks on Rocky Shores. Freeman.

Stewart, J.E. and L.J. Marks. 1978. Distribution and Abundance of Hydrocarbon-Utilizing Bacteria in Sediments of Chedabucto Bay, Nova Scotia, in 1976. J. Fish. Res. Board Canada 35. Special Issue - Recovery Potential of Oiled Northern Marine Environments.

Strahler, A.N. 1971. The Earth Sciences 2nd Edition. Harper & Row, New York, N.Y.

Straughan, D. (compiler). 1971. Biological and Oceanographical Survey of the Santa Barbara Channel Oil Spill 1969-1970. Volume I Biology and Bacteriology. Allan Hancock Foundation, University of Southern California.

Sutherland Brown, A. 1968. Geology of the Queen Charlotte Islands. Bulletin No. 54. British Columbia Department of Mines and Petroleum Resources. Victoria, B.C.

Swift, W.H. April 1970. Review of the Santa Barbara Oil Pollution Incident, Battelle Memorial Institute, Richland, Washington.

Symposium: January 21-24, 1980. Research on Environmental Fate and Effects of Drilling Fluids and Cuttings. Volumes I and II. National Oceanic and Atmospheric Administration and Environmental Protection Agency.

Szaro, R.C. and P.H. Albers. 1977. Effects of External Applications of No. 2 Fuel Oil on Common Eider Eggs. In D.A. Wolfe (editor), Fate and Effects of Petroleum Hydrocarbons in Marine Organisms and Ecosystems. Pergamon Press.

Tait, R.V. 1968. Elements of Marine Ecology. Butterworth Publ. Co.

Tabata, S. 1980. An Inventory of Physical Oceanographic Information for the Waters of Queen Charlotte Sound, Hecate Strait, Dixon Entrance and their Vicinity. Institute of Ocean Sciences, Sidney, B.C.

Tabata, S., [illegible] McAllister, [illegible] Coombs, W. Atkins and H.J. Hollister. [illegible]. Oceanographic Record, Ocean Station P, January [illegible] to [illegible] September [illegible], [illegible]. J. Fish. Res. Board Canada M.S. Rept. Ser. No. [illegible].

Thayer, G.W., D.A. Wolfe, and R.B. Williams. 1975. The Impact of Man on Seagrass Systems. American Scientist Volume 63.

[illegible], S. Storms are a Major Cause of Mobile Rig Mishaps Offshore. Offshore, June 5, 1976.

Thomas, D.J. 1979. The Effect of Discharge Drilling Fluid Waste on Primary Productivity at [illegible], Inuvik, N.W.T. Prepared for Canadian Marine Drilling Ltd., Arctic Lab. Ltd.

Thomas, M.L.H. 1973. Effects of Bunker C Oil on Intertidal and Lagoonal Biota in Chedabucto Bay, Nova Scotia. J. Fish. Res. Board Canada 30.

Thomas, M.L.H. Communities and Ecosystems. In J.B. Sprague, J.H. Vandermeulen and P.G. Wells (eds.) Oil and Dispersants in Canadian Seas - Research Appraisal and Recommendations. A report prepared for the Environmental Protection Service, Environment Canada. Advance copy.

Thompson, J.R. 1977. More Information Required About Effects of Oil Pollution. Australian Fisheries, November 1977.

Thomson, R.E. 1981. Oceanography of the B.C. Coast. Canadian Special Publication in Fisheries and Aquatic Sciences. 56.

TMPLC. See Trans Mountain Pipe Line Company Limited.

Todd, M.B. 1980. Development of Beaufort Sea Hydrocarbons - An Opportunity for Canadian Industry. Prepared for workshop on "Frontier Oil and Gas Development - The Decade Ahead", Montebello, Quebec.

Trans Mountain Pipe Line Co. Ltd. 1980a. National Energy Board Submission prepared by IEL and ESL - Volume XVI. Marine Resources Inventory and Impact Assessment Report. Sidney, B.C.
also: Map Folio, Volume XVII. Biological Resources of Coastal and Offshore B.C. - Inventory and Analysis of Sensitivity to Oil Spills.

Trans Mountain Pipe Line Co. Ltd. 1980b. Physical/Chemical Oceanography Inventory, West Coast British Columbia. Prepared for Trans Mountain Pipe Line Co. Ltd., Vancouver, B.C. by J.W. McDonald and T. Jandali, ESL Environmental Services Ltd., Vancouver, B.C.

U.S. Coast Guard. 1978. Phase II Statement of Evidence. West Coast Oil Ports Inquiry.

U.S. Department of Energy. 1979. Petroleum Supply Alternatives for the Northern Tier and Inland States Through the Year 2000. Volume I Executive Summary and Findings. Washington, D.C.

U.S. Department of the Interior, U.S.G.S. 1976. An Oil Spill Risk Analysis for the Mid-Atlantic OCS Lease Area. 1976. Oil Spills 1971-1975, Gulf of Mexico - Outer Continental Shelf. U.S.G.S.-741.

U.S. Department of the Interior. 1981. Final Outer Continental Shelf Orders Governing Oil and Gas Lease Operations in the Arctic. (Federal Register). U.S. Government Printing Office, Washington.

U.S. Department of the Interior, Bureau of Land Management. June 1981. Draft Environmental Impact Statement. Proposed Outer Continental Shelf Oil and Gas Lease Sale, Norton Sound, Alaska.

Vandermeulen, J.H. (Chairman of Symposium), and J.C. Stevenson, (eds.). May, 1978. Recovery Potential of Oiled Marine Northern Environments. Journal of the Fisheries Research Board of Canada, Special Issue, Vol. 35, (5).

Vandermeulen, J.H. 1982. Oil Spills: What Have We Learned? In J.B. Sprague, [illegible] Environmental Protection Service, Environment Canada, Ottawa (1982).

Vandermeulen, J.H. and W.R. Penrose. 1978. Absence of Aryl Hydrocarbon [illegible] Special Issue: Recovery Potential of Oiled Marine Northern Environments.

Varanasi, U. and D.C. Malins. 1977. Metabolism of Petroleum Hydrocarbons: Accumulation and Biotransformation in Marine Organisms. In D.C. Malins (ed.), Effects of Petroleum on Arctic and Subarctic Marine Environmental and Organisms. Volume II, Biological Effects. Academic Press Inc., New York.

Vermeer, K. and R.W. Campbell (in press). Distribution of Densities of Marine Birds Along the British Columbia Coast. Canadian Wildlife Service, Delta and B.C. Provincial Museum.

Vermeer, K. and R. Vermeer. 1975. Oil Threat to Birds on the Canadian West Coast. Canadian Field Naturalist Vol. 89.

Vernberg, F.J. and W.B. Vernberg. 1974. Pollution and Physiology of Marine Organisms. Belle W. Baruch Institute for Marine Biology and Coastal Research. Academic Press University of South Carolina.

Waldichuk, M. 1968. Waste Disposal in Relation to the Physical Environment - Oceanographic Aspects. Syesis Vol. 1.

Waldichuk, M. 1978. Some Marine Environmental Effects of Oil Pollution. Appendix E. In: Potential Pacific Coast Oil Ports: A Comparative Risk Analysis. Vol. II Supplementary Appendices. Prepared by Working Group on West Coast Deepwater Oil Ports, Vancouver.

Ward, C.H., M.E. Bender, and D.J. Reish, (editors). 1979. The Offshore Ecology Investigation: Effects of Oil Drilling and Production in a Coastal Environment. Rice University Studies, Vol. 65 No. 4 and 5.

Ward, J.G. and C.E. Tull. Scientific Studies to be Conducted in Response to an Oil Spill in the Beaufort Sea. For Institute of Ocean Sciences, Patricia Bay. LGL Ltd., Edmonton.

Westlake, D.W.S. and F.D. Cook. 1980. Petroleum Biodegradation Potential of Northern Puget Sound and Strait of Juan de Fuca Environments. Prepared for Office of Energy, Minerals and Industry Office of Research and Development, U.S. Environmental Protection Agency.

Wickett, W.P. 1973. Unusually Strong Currents in Hecate Strait, 1968. Fisheries Research Board of Canada, Nanaimo, B.C.

Williams, [illegible] and [illegible]. 1979. Onshore Impacts of Offshore Oil: A [illegible]. Prepared for the Office of Policy Analysis, U.S. Department of the Interior.

Wilson, K.W. 1972. Toxicity of Oil-Spill Dispersants to Embryos and Larvae of Some Marine Fish. In Mario Ruivo (ed.) Marine Pollution and Sea Life. F.A.O. London.

Wiseman, R.J., J. Payne and S. Akenhead. 1981. Recruitment Variability - Can We Detect the Effect of Oil Pollution? In Consultation on the Consequences of Offshore Oil Production on Offshore Fish Stocks and Fishing Operations. CAFSAC Secretariat, Bedford Institute of Oceanography.

Wolfe, D.A. (ed.). 1977. Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms - Proceedings of a Symposium, November 10-12, 1976, Seattle, Washington. Pergamon Press.

Wolferstan, W.H. 1981. Oil Tanker Traffic: Assessing the Risks for the Southern Coast of British Columbia. APD Bulletin 9, Ministry of Environment, Province of British Columbia.

Wood, B. 1973. Oil Spills From A Northern Pipeline. Institute of Environmental Sciences and Engineering, University of Toronto.

Woodson, R.D., M.J. Tannen, and J.C. Corbett. 1979. Local Control over the Onshore Impacts of Offshore Energy Development in Florida. Technical Paper No. 13. University of Florida, Holland Law Center.

Worbets, B.W. 1979. Shoreline Oil Spill Protection and Cleanup Strategies - Southern Beaufort Sea. Manual and Appendix.

Zingula, R.P. and D.W. Larson. 1977. Fate of Drill Cuttings in the Marine Environment. Ninth Annual Offshore Technology Conference, Houston Texas, May 2-5. Papter #OTC 3040.

Zinn, J. 1978. Environmental Planning for Offshore Oil and Gas, Volume II: Effects on Coastal Communities. The Conservation Foundation, Washington, D.C. U.S. Fish and Wildlife Service, Biological Services Program, FWS/OBS 77/13.

# GLOSSARY

# GLOSSARY OF TERMS

ANNULUS - Space between the walls of the drill hole and the casing pipe; often filled with cement.

AVOIDANCE THRESHOLD - The level of contamination at which an organism will begin avoidance behaviour.

BACKSHORE - That section of the shore landward of the high water mark.

BIOAVAILABILITY - Availability to living organisms; usually refers to nutrients.

BIOCHEMICAL OXYGEN DEMAND (BOD) - Consumption of oxygen by organisms which act on effluents or nutrients in the water to the point where oxygen may become a limiting factor.

BIOGENIC - Generated by biological activity.

BLOWOUT - an uncontrolled flow, or "kick", of oil or gas and other fluids from a drilling rig; caused when pressures within the formation overcome the counterpressures of drilling fluids and safety devices designed to prevent blowouts.

B.O.P. STACK - Blowout Preventer Stack; a safety device mounted on the seabed which can shut off the flow of oil and/or gas when an emergency occurs.

BODY BURDENS - The level of hydrocarbons present in live body tissues.

CASING - Lengths of steel pipe which are cemented into position within the drill hole.

CHRISTMAS TREE - A series of valves mounted on a platform deck which can control or seal off the flow of oil and/or gas.

CONTINGENCY - A possibility that must be prepared against; future emergency.

CORIOLIS EFFECT - An apparent force on moving particles resulting from the earth's rotation; deflection is to the right of motion in the Northern Hemisphere and to the left in the Southern Hemisphere; the effect is proportional to the speed and latitude of the moving particle and results from the conservation of motion against the rotation of the earth.

DEPURATE - To cleanse or purge; to rid body tissues of accumulated impurities.

DOWNWELLING - The seaward entrainment of water from surface to depth as a result of surface water being driven shoreward by winds blowing parallel to the shore ("up" the coast for the west coast); may also be caused by the convergence of surface currents.

DRILLING FLUID - A specially formulated "mud" (thick liquid) which cools and lubricates the drill bit, carries rock cuttings to the surface, and acts as a safety device against blowouts.

ENTRAINMENT - In fluid mechanics, the replacement by a mass of water by another that has been displaced; to pull or draw along.

FORESHORE - That section of the shore between the highest and lowest tides.

GYRE - See Vortex.

HALOCLINE - A region in the water column where there is a relatively rapid change in salinity.

INFAUNA - Organisms that live in sediments (e.g., clams).

INVERSION - a state in which the air temperature increases with increasing altitude, holding surface air down along with its pollutants.

ISOTHERMIC - Being of uniform temperature throughout.

LANDFALL SITE - The point at which a marine pipeline comes ashore.

L.P.G. - Liquifiable Petroleum Gas.

LITHOSPHERIC PLATE - A tectonic plate (q.v.).

LITTORAL DRIFT - The movement of sediments parallel to the shore under the influence of waves, currents, tides, and estuarine flows.

LONGSHORE DRIFT - Transport of beach materials parallel to the shore through the action of longshore currents.

MARINE RISER - A hollow tube in which the drill string rotates and which decends from the drill ship to the ocean floor.

MONITORING - The field activity that entails the periodic or continuous collection of data to measure environmental change.

OFFSHORE - That section of the shore seaward of the low water mark.

OIL RETENTION POTENTIAL (ORP) - An index of shoreline susceptibility to oil spills, based on the geological and geohydraulic characteristics of a particular coastal area.

PARTIAL PROCESSING - The method by which free and emulsified water, dissolved solids and suspended solids are removed from the well stream.

o/oo - Parts per thousand.

PELAGIC - Seagoing; living at sea or in the open ocean as opposed to areas near shore.

PRIMARY PRODUCTIVITY - The production of organic matter from inorganic nutrients by organisms through photosynthesis; may also refer to the amount of organic matter thus synthesized.

REAL TIME - With regard to information gathering, being available for analysis or interpretation synchronously or at or near the same time as the event from which the information is being gathered.

SILL - A ridge of glacially deposited material often found at or near the mouths of inlets.

SPECIAL WASTES - Those wastes which due to their nature and quantity are potentially hazardous to human health and/or the environment and which require special disposal techniques to eliminate or reduce th hazard.

SPRING TIDE - The tide generally having the greatest rise and fall, occurring at or shortly after the new or full moon, and coinciding approximately with the vernal equinox.

S.C.F.D - Standard cubic feet per day: a measurement of gas flow volume.

STORM CHOKE - A subsurface safety device which can seal off the flow of oil and/or gas from the well.

STRANDFLAT - A flat, coastal plain fronting a high, fjord-like coast.

TECTONIC PLATE - A large, relatively rigid section of the earth's crust which overlies the denser material of the mantle; separated from other plates by faults and ridges.

THERMOGENIC - Generated by heat.

TIDAL EXCURSION - The movement, by means of tidal forces, of material in the water column from a mean position in an alternating or oscillating motion.

UPWELLING - The shoreward entrainment of cold, oxygen-poor, nutrient-rich water from depth to surface to replace surface water that has been driven seaward by winds blowing parallel to the shore. The latter effects is based on the observation that the net drift of a column of water is 90° to the right of wind direction in the Northern Hemisphere; may also result from the action of currents on a submarine prominence.

VORTEX - Fluid flow around a central axis.

WAVE-ENERGY ENVIRONMENT - The degree of exposure of a coastal area to oceanic influences.

# APPENDICES

# APPENDIX I
# PROJECT TIMETABLE

| | |
|---|---|
| July 6/81 | Project received from Ministry of Environment executive by Assessment Branch and assigned to Evaluation Section, J.P. Secter, Manager. |
| July 17/81 | PEA team selected and assigned.<br>Dr. Robert W. Langford, Assessment Branch<br>Editor and Project Coordinator, Overall and Chapter 6<br>Ken Baillie, Assessment Branch<br>Offshore Petroleum Development, Chapter 1<br>Jim Slater, Assessment Branch<br>Offshore Physical Environment, Chapters 2 and 5<br>Don Tillapaugh, Marine Resources Branch, and<br>Ken Turner, Assessment Branch<br>Offshore Biological Environment, Chapter 3<br>Susan Abs, Assessment Branch<br>Onshore Environmental Impacts, Chapter 4<br>W.H. Wolferstan, Assessment Branch<br>Offshore Risks, Chapter 5<br>Rona Stewart, Assessment Branch, Editorial Assistant |
| April 28-30/81 | Visit to St. John, Newfoundland by J.P Secter for discussions with Newfoundland Petroleum Directorate, and examination of Mobil offshore drilling operations. |
| August 25-27/81 | Field trip and overflight of North Coast and Queen Charlotte Islands by Jim Slater, Ken Turner and Bill Wolferstan. Extensive videotape footage taken for use by team and Branch. |
| September 20-24/81 | Visit to Juneau, Anchorage and Kenai, Alaska by J.P. Secter re offshore oil and gas development. |
| September 22-27/81 | Field trip to Prince Rupert and Queen Charlotte Islands by Susan Abs. |
| October 2-12/81 | Participation by Dr. R. Langford with East-West Environment and Policy Institute in Honolulu for Preparation of Guidelines for Social and Environmental Management of Offshore Hydrocarbon Exploration and Development. |
| January 15/82 | Draft I of P.E.A. circulated. |
| January 19-20/82 | Field trip to Smithers by R. Langford for discussions with regional M.O.E. staff. |

| | |
|---|---|
| February, 1982 | Report contracted by Ministry of Environment from McLaren Plansearch re Environmental Management of Offshore Development. |
| April 22/82 | Initiation by Assessment Branch of an Offshore Environmental Studies Forum (Provincial Agencies, Federal Agencies, Universities and Industry). |
| May 13-14/82 | Workshop on "Offshore Drilling" for public interest groups in Nanaimo, B.C. Attended by Susan Abs. |
| May 25-26/82 | Ministry of Environment sponsored Seminar on introduction to Offshore Exploration and Development featuring Polar Tech Ltd. and Woodward-Cldye Ltd. |
| June 18/82 | Draft II of P.E.A. submitted for review by Assessment Branch Management. |
| July 19/82 | Draft III submitted for sign off by Assessment Branch. |
| September 20/82 | Draft IV P.E.A. conveyed to Assistant Deputy Minister for review. |
| December 1/82 | P.E.A. completed. |

# APPENDIX II
# INFORMATION CONTACTS

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# APPENDIX III
# DISPERSANT USAGE REGULATIONS
# (FROM OIL SPILL INTELLIGENCE REPORT, 1982)

## UNITED KINGDOM

A 1981 report by the U.K. Royal Commission on Environmental Pollution (RCEP) entitled "Oil Pollution of the Sea" summarizes the U.K. policy on dispersant use with the following: "Generally, where an oil spill is not causing or threatening damage, it is preferable for it to be allowed to evaporate and degrade naturally. Although the use of dispersants will for the present continue to form the basis of the response capability at sea, it will ... be initiated only where there is in the judgment of experts, a significant threat of damage to birds or marine life on the coast, or where an operator considers it necessary for safety reasons." (OSIR, 19 Mar., 1982, p.2.).

Under the 1974 Dumping at Sea Act, local authorities in the U.K. are permitted to use dispersants after obtaining a license from the Ministry of Agriculture, Fisheries and Food (MAFF); however, they are required to use only dispersants licensed by the MAFF on the basis of standardized toxicity and efficiency tests, and to consult a District Fisheries Officer if they plan to use the dispersants in water shallower than 20 meters. Government agencies such as the U.K. Department of Trade's Marine Pollution Control Unit are exempt from the statutory requirements of the 1974 Dumping Act but, according to the RCEP, are "expected in practice to use only licensed products." To date, the MAFF has licensed a total of 35 dispersant concentrates and 46 dispersants with a hydrocarbon solvent base.

To apply for a MAFF dispersant license, a dispersant manufacturer must first submit the dispersant to the Warren Springs Laboratory in Stevenage, U.K., for efficiency testing under laboratory and field conditions. In the laboratory efficiency test, the dispersant is agitated in a flask of seawater with a test volume of oil, and it must keep 30 to 80 percent of the oil in emulsion after the mixture is left standing for a specified time period. In the field test, a volume of dispersant is sprayed from a boat onto a test oil slick of equal volume and is agitated with breaker boards. For the dispersant to pass the field test, the treated oil must disappear from the water surface within about 5 minutes. In addition to meeting efficiency standards, the dispersant must not contain any benzene, chlorinated hydrocarbons, caustic alkali, or other specified chemicals, and must have a phase separation limit below -5°C, a flash point above 61°C, and a low viscosity at 0°C. A Warren Springs spokesman told OSIR that the facility tests about 15 dispersants per year.

The dispersant must also pass the MAFF toxicity test, which required the oil-and-dispersant mixture to be no more toxic to marine organisms than the oil alone. In the MAFF Fisheries Laboratory at Burnham-on-Crouch, a standard oil and a mixture of the standard oil and the test dispersant are mechanically mixed in separate seawater tanks containing brown shrimp, and then the shrimp mortality in both tanks is measured and compared. In another toxicity test, the MAFF researchers expose the common limpet, an intertidal organism, to the test dispersant and to the standard oil, and then measure and compare the subsequent mortalities produced by each substance. The MAFF laboratory decided not to use a mixture of dispersant and oil in this test because the mortality of limpets exposed to the oil alone is so high that any additional mortality due to the dispersant would be difficult to detect.

The RCEP report observes that operational factors, such as the time required for dispersant application vessels to reach an offshore slick, the difficulty in sighting a slick during the poor weather conditions associated with tanker casualties, and the limited rate at which vessels can apply dispersants on slicks, have caused some experts to comment that in some incidents "coastal pollution would not have been appreciably worse if dispersants had not been used at all." The RCEP recommends that Warren Springs Laboratory continue to develop a data base on the response of different oil types to different dispersants and that work continue on computer models predicting slick behavior in order to "improve the quality of decisions on cleanup options."

## NORWAY

In February 1980, the Norwegian Ministry of the Environment promulgated a set of dispersant regulations requiring product toxicity and efficiency tests identical to those performed at the Warren Springs Laboratory. The regulations contain similar standards for physical and chemical characteristics, such as the absence of toxic and carcinogenic aromatic and chlorinated hydrocarbons, phenols, and cresols. The Norwegian toxicity tests are identical to the MAFF tests, except that they include a test of the dispersant's toxicity to cultures of a unicellular algal species.

The Norwegian regulations prohibit dispersant use in the following locations and situations: in freshwater streams; on slicks thicker than 0.5 centimeters; on diesel or other "fluid oil" slicks; on viscous slicks at low temperatures; on emulsified oil; on small, open-ocean spills; and in ice-infested waters, where the presence of ice limits the effectiveness of the dispersant application. Response personnel interested in using more than 1000 liters of dispersants or in applying dispersants in the nearshore zone must first obtain permission from the Norwegian State Pollution Control Authority. The regulations do not, however, govern the use of approved dispersants on spills representing fire or explosion hazards.

## SWEDEN

Dispersant use "has been and is still under dispute" in Sweden, according to Commodore Roland Engdahl, former head of the Swedish Coast Guard (SCG). The SCG and the Swedish Environmental Protection Board (EPB), working with the Swedish Water and Air Pollution Research Institute (IVL) in Karlskrona, have developed dispersant guidelines emphasizing the use of dispersants when mechanical recovery is not possible and when the slick covers a wide area. Engdahl said that the guidelines advise against the use of dispersants in environmentally sensitive areas and in bodies of water with a low turnover, and prohibit their use in freshwater lakes that serve as drinking water sources. The SCG on-scene commander has the authority, however, to use dispersants in these areas to prevent the spilled oil from impacting seabird colonies or, as in Norway, to reduce fire or explosion hazards.

The IVL told OSIR that the dispersant controversy in Sweden has subsided because the SCG has used such a small volume of dispersants recently and also because most dispersant operations occur offshore and away from public view. In fact, during each of the last 3 years, the SCG has used about 25 metric tons of dispersant in an average of 4 to 5 responses per year.

Although Sweden has no formal regulations on dispersant acceptance, according to the IVL, the EPB currently recommends the use of only 2 dispersants, American Petrofina Inc.'s Finasol OSR2 and BP Detergents Ltd.'s BP 1100X. The EPB is awaiting the completion of an IVL research program on dispersants before developing its guidelines for dispersant use in the Baltic Sea. IVL is currently conducting experiments to determine the toxicity of various dispersants to Baltic Sea organisms and also the effectiveness of those dispersants in the low salinity and low temperature environment of the Baltic Sea. The IVL is also studying the biodegradation and weathering of dispersant and oil mixtures in the oxygen-poor Baltic Sea waters.

## JAPAN

Dispersant use remains a controversial issue in Japan, despite a dispersant acceptance test program mandated by the 1970 Law Relating to the Prevention of Marine Pollution and Maritime Disaster and dispersant use guidelines promulgated in 1974 by the Japanese Ministry of Transport (MOT). S. Takenaka of the Japan Maritime Disaster Prevention Center in Tokyo told

OSIR that the majority of the fishing industry remains opposed to dispersant use and concerned over the toxicity of dispersants in the water column. He said that the fishermen were concerned about the precipitation onto the sea floor of chemically treated oil, which they argue can taint commercially valuable fish and shellfish.

In Japan, accepted dispersants must meet physical, chemical, and efficiency standards similar to those specified at Warren Springs, including: a flash point above 75°C, a low viscosity at 30°C, a 60 percent emulsion rate in 30 seconds, and high biodegradability. For a dispersant to pass the toxicity test, a culture of the coastal phytoplankton Skeletonema costatum must show no mortality after a one-week exposure in vitro to a 100 parts per million (ppm) solution of the dispersant alone in seawater. In addition, more than 50 percent of a test group of killfish must survive a 24-hour exposure to a 3000 ppm solution of the dispersant alone in seawater. The Maritime Safety Test and Research Center retests on an annual basis all dispersants sold in Japan, and a committee annually reviews new developments to update the dispersant standard regulations.

According to Takenaka, the MOT regards dispersant use as the last resort, except where there is serious damage or imminent threat thereof to human life or property. The MOT guidelines prohibit the use of dispersants on light or fluid oils, on tarry or viscous slicks, and in environmetally sensitive areas. The guidelines recommend that response workers use spray equipment to apply dispersants and "sufficiently" agitate the slick following application. In addition, the guidelines recommend that the volume of dispersant used should not exceed 20 to 30 percent of the spill volume.

## BRAZIL

Brazilian dispersant usage policy began to develop in January 1978, when the Liberian tanker Brazilian Marina struck a rock in the Sao Sebastiao Channel off the state of Sao Paulo, Brazil, and ruptured 2 cargo tanks, spilling about 10,000 tons of oil. Northeasterly winds and currents carried the oil onto 120 kilometers of beach in the states of Sao Paulo and Rio de Janeiro. Brazilian response authorities applied about 5500 gallons of the Brazilian dispersant BRAS-Z-Plus on 20 kilometers of amenity beaches before contracting with the Companhia de Tecnoligia de Saneamento Ambiental (CETESB) in Sao Paulo to coordinate a scientific response to the cleanup operation.

CETESB, with the assistance of the U.S. Coast Guard (USCG) and the U.S. Environmental Protection Agency (EPA), analyzed the chemical composition of the BRAS-X-Plus and tested the dispersant's toxicity on brine shrimp and phytoplankton. They found that the dispersant was "extremely toxic" and was more toxic alone than when mixed with the crude oil. CETESB recommended that the response authorities stop using the dispersant before they applied it to several fisheries and caused severe environmental damage. CETESB noted, however, that the dispersed oil on the beaches penetrated deeply into the sand and persisted for at least 6 months after the spill.

A CETESB spokesman told OSIR that, following the Brazilian Marina incident, the Brazilian government contracted with CETESB to develop dispersant usage guideline as well a dispersant acceptance standards and tests. CETESB, which prepared a preliminary oil spill contingency plan for the State of Sao Paulo in 1981, plans to establish a nationwide dispersant usage and acceptance policy by 1983. (OSIR, 25 Dec., 1981, p.3.). The CETESB spokesman also said that CETESB has used the Warren Springs and MAFF methods to test the toxicity and efficiency of 15 Brazilian dispersants. He added that Brazilian response authorities do not use dispersants manufactured outside Brazil because import costs are prohibitive.

The Brazilian national oil company, Petroleo Brasileiro S.A. (PETROBRAS), currently allows the use of biodegradable, nontoxic dispersants when the spill takes place in deep water or when mechanical recovery is not possible, according to a PETROBRAS spokesman. PETROBRAS does not allow, however, the use of dispersants in mangroves, estuaries, shallow waters, or freshwater areas.

## CHILE

The 1978 Chilean Law of Navigation gives the Directorate of Maritime Territories and the Merchant Marine, a branch of the Chilean Navy similar to the USCG, the authority to permit the use of dispersants on a case-by-case basis. According to Directorate Commandant Francisco Pizarro, the Directorate decides whether to place the dispersant on an approval list on the basis of in vitro and field toxicity tests. The Oceanology Institute of the University of Valparaiso conducts these tests using local fish and shellfish species under ambient salinity and temperature conditions.

The Directorate authorizes the use of a specific dispersant in each spill incident on the bases of the product's laboratory performance under similar conditions. The use of toxic products is limited to offshore, high-current areas where rapid mixing minimizes the impact of the dispersant on marine organisms. Commandant Pizarro told OSIR that 3 dispersants - Dasic International Ltd.'s Slickgone L.T.E. Concentrate, Exxon chemical Co.'s COREXIT 9527, and BP Detergent Ltd.'s BP 1100 WD Concentrate - are the only products currently on the approval list.

According to ENAP, the Chilean national oil company, dispersant usage in Chile is not controversial because "dispersants have practically never been used." An oil refinery manager on Concon, Chile, told OSIR, however, that Directorate response teams have used small volumes of dispersants in bays and beaches following minor spills. Commandant Pizarro told OSIR that the last time that the Directorate used dispersants on a large scale took place during the 7 July 1978 spill of 13,000 cubic meters of crude oil from the grounded Chilean tanker Cabo Tamar off the central coast of Chile near Talcahuano. (OSIR. 23 Mar., 1979, p. 18.) Pizarro told OSIR that repsonse workers immediately applied 5500 gallons of COREXIT 9527 and BP 1100 WD Concentrate to disperse the slick offshore, but that oil still impacted 7 kilometers of beach.

## ARABIAN GULF

The Arabian Gulf nations have no legally mandated regulations for dispersant use, according to OSIR industry sources. The Gulf Areas Oil Companies' Mutual Aid Organization (GAOCMAO), however, requires its 19 member companies to sign an agreement to use only dispersant products that conform to Warren Springs specifications and MAFF toxicity standards. In the Gulf, GAOCMAO maintains dispersant stockpiles from which any member company may draw when a spill incident exceeds the company's own resources. A GAOCMAO spokesman said that, although GAOCMAO does not impose dispersant usage regulations on its members, individual companies develop their own contingency plans, designating fish breeding grounds and shallow waters as unsuitable for dispersant use. An industry spokesman told OSIR that most operators in the Gulf use dispersants as the "number one response" to oil pollution incidents.

Saudi Arabia and Kuwait are preparing dispersant usage regulations as part of their national contingency plans. An industry source told OSIR that the oil companies operating in the Arabian Gulf would welcome official dispersant usage regulations because such regulations would limit their responsiblity for determining when to use dispersants in a response action.

## CANADA

In 1973, the Canadian Environmental Protection Service (EPS) released a document entitled "Guidelines on the Use and Acceptability of Oil Spill Dispersants," and established a government laboratory to evaluate the performance of dispersants submitted for use in Canada and to develop a list of accepted dispersants. Under these guidelines, the EPS, with the approval of Environmental Management Service and the Canadian Fisheries and Marine Service, has the authority to permit the use of dispersants on a case-by-case basis.

Some provinces have developed their own dispersant usage regulations. For example, Alberta prohibits the use of dispersants in any freshwater area. If a spill occurs in a province with its own dispersant usage regulations and if response personnel are considering the dispersant option, the EPS must first obtain approval from the relevant provincial authorities before authorizing the use of dispersants there.

The EPS guidelines restrict the use of dispersants to only those products on the acceptance list and advise on-scene coordinators to avoid dispersant usage in the following areas: major fisheries; breeding or migratory areas for fish, birds, and other species; drinking or industrial water sources; low-volume or low-flow water bodies; and sandy beaches or nearshore zones with sensitive flora and fauna.

The guidelines specify that "dispersants may be used only when other methods are not reasonably effective" and when the "proper" mixing and application equipment are available. In addition, before making a decision to use dispersants, the on-scene coordinator must consult the EPS effectiveness rating for the dispersant under consideration to determine whether the dispersant is effective under the existing field conditions. The on-scene coordinator also must initially use a "minimum quantity of the dispersant to verify its effectiveness before continuing its use and must apply "only the strict minimum ... to correct the condition for which approval was given." The guidelines require the on-scene coordinator to report the following information to the EPS: the type and amount of dispersant used, the method of dispersant application, the behavior of the dispersed oil, and the environmental conditions during the response.

The acceptability criteria in Canada, like those in the U.K. and Japan, prohibit the use of dispersants containing caustic alkali and free mineral acids; however, the criteria allow the use of dispersants containing limited concentrations of chlorinated hydrocarbons, aromatic hydrocarbons, and some heavy metals. To satisfy the EPS dispersion stability criterion for acceptability, a dispersant which has been mixed with No. 2 fuel oil in a dispersant/oil ratio of 1 to 3 must keep 60 percent of the oil in emulsion for 6 hours at 15°C. To satisfy the EPS effectiveness criterion, the dispersant must disperse 65 percent of a series of test slicks of No. 2 fuel, crude oil, medium bunker fuel, and heavy bunker fuel oil in 10 minutes at 5°C and 15°c temperatures and with a volume not exceeding the volume of the slick. Unlike the U.K. and Japanese dispersant acceptance standards, the EPS criteria do not specify such physical characteristics as flash point and viscosity.

The EPS toxicity criteria for acceptability requires that at least 50 percent of a test population of rainbow trout exposed for 96 hours to a dispersant must survive in dispersant concentrations of no less than 1000 milligrams (mg) per liter of water. In addition, at least 50 percent of a test population of rainbow trout exposed for 96 hours to a mixture of equal volumes of the dispersant and No. 2 fuel oil must survive in oil/dispersant concentrations of no less than 100 mg per liter of water. Although the EPS uses rainbow trout as its test species, it also accepts toxicity tests performed with "non-standard" species of sport fish or commercially valuable fish or invertebrates. The EPS list of accepted dispersants currently consists of the following 4 products: BP 1100X, COREXIT 8666 and COREXIT 9527, Diachem Industries Ltd.'s Oilsperse 43, and Drew Chemical Corp.'s Soil Spill Dispersant/LT.

An EPS spokesman told OSIR that the agency is revising its current guidelines to reflect the increased data available on dispersant behavior and effectiveness in real and test spills. The spokesman said that the revised guidelines will include simplified toxicity and effectiveness tests to allow for the "routine, inexpensive use" of those tests. In addition, the revised guidelines, which EPS plans to promulgate by late 1982, will include a "working set of considerations" about the relative merits of dispersant usage during spill cleanups in muddy or sandy sediments.

UNITED STATES

Dispersant usage regulations in the U.S. currently appear as Annex X of the Carter Administration's 1980 National Oil and Hazardous Substances Pollution Contingency Plan (NCP), prepared under the mandate of the 1977 Clean Water Act. According to Annex X, before the EPA will consider listing a dispersant as accepted for use in a spill response, the manufacturer must submit data on the chemical, physical, and toxic characteristics of the dispersant and also on the performance of that dispersant in a standardized EPA effectiveness test.

In the U.S., as well as in the U.K., Japan, Canada, and other countries regulating dispersant use, official acceptance of a dispersant does not mean approval to use that dispersant in any spill situation, but rather that the authorities may decide to use that product. In the NCP, the on-scene coordinator can decide to use accepted dispersants for the following reasons: to reduce or prevent environmental and human health hazards, to minimize or prevent the impact of a spill on vulnerable waterfowl populations, and to minimize a spill's "interference with designated water uses." The current EPA acceptance list contains 18 dispersants.

The 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) established new regulations for government responses to oil and hazardous substances spills, and required the EPA to revise the NCP to incorporate the CERCLA regulations. (OSIR, 21 May, 1982, p.1.) As part of its revisions, the EPA proposes to eliminate Annex X and substitute Subpart H, a broad statement giving the EPA the authority to approve dispersants on a case-by-case basis with one of the current NCP requirements and without being limited to a list of accepted dispersants.

Although industry representatives commented to the EPA that Subpart H should contain even less regulation by allowing on-scene coordinators to decide on dispersant usage during a spill, environmental organizations criticized the revised NCP for giving decision-makers "absolutely no guidance" on whether to use dispersants. The environmental groups also criticized the elimination of the product data requirements, which they argued will reduce emphasis on the development of nontoxic dispersants. The EPA must promulgate a final NCP by 16 July, but has not indicated whether it will reinstate the original dispersant use regulations, including the list of accepted dispersants.

The American Society for Testing and Materials F-20.13 Committee, known as the Dispersant Use Guidelines Task Force, is developing guidelines for dispersant response planning and for making on-scene decisions on whether to use dispersants in coral reefs, seagrass beds, marine mammal habitats, rocky shores, and bird habitats. The new guidelines, which consider dispersant usage a valid response technique and not a "last resort," are based on the assumption that the dispersant to be used in a response is effective when correctly applied. In a paper on dispersant response planning to be presented at the upcoming Arctic Marine Oilspill Program Technical Seminar in Edmonton, Alberta, David Betts of Petro-Canada and Richard Golob of OSIR, contend that, "as dispersants become less toxic and as dispersant application techniques become more refined, response planners will need to give dispersants the same attention now given to mechanical equipment."